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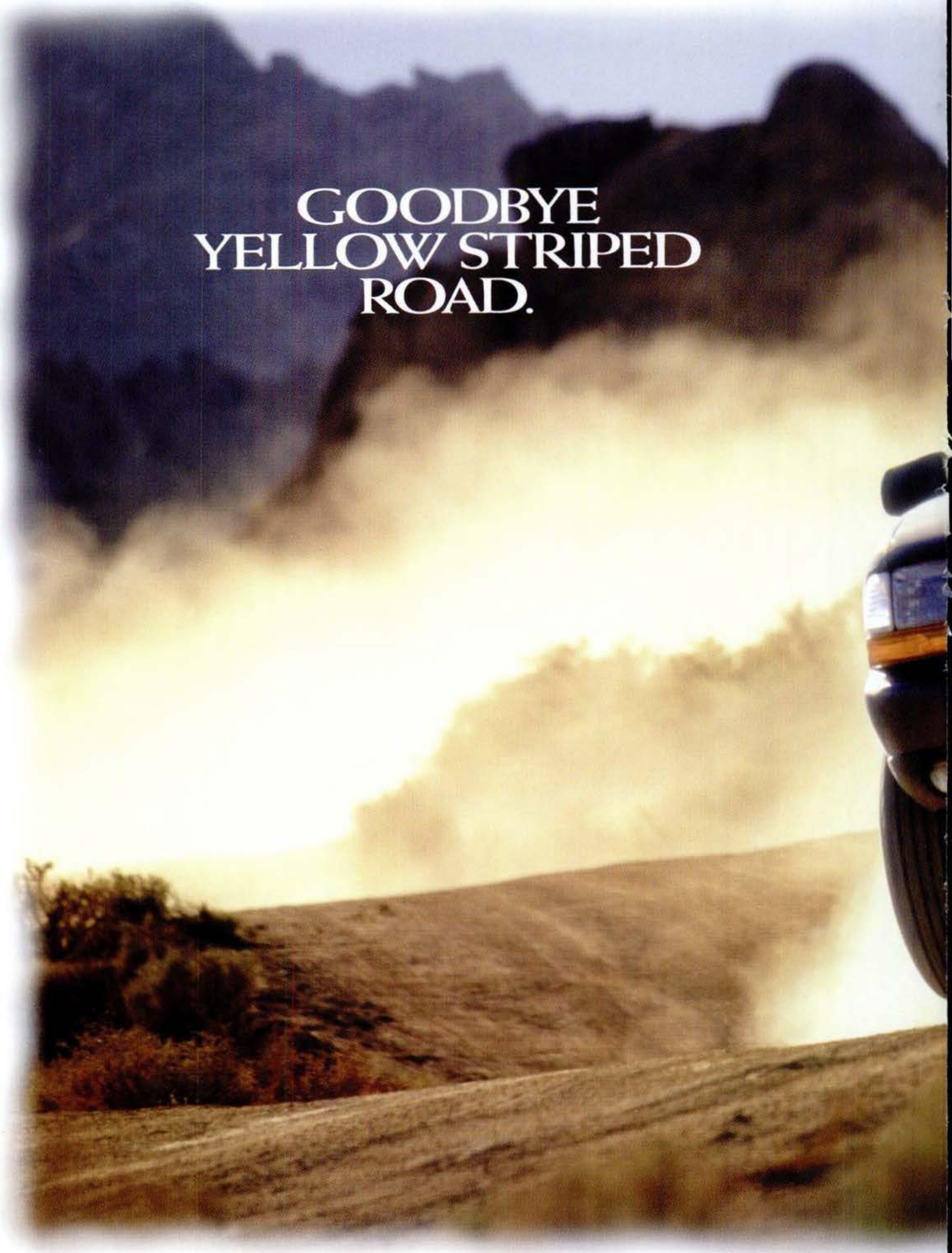

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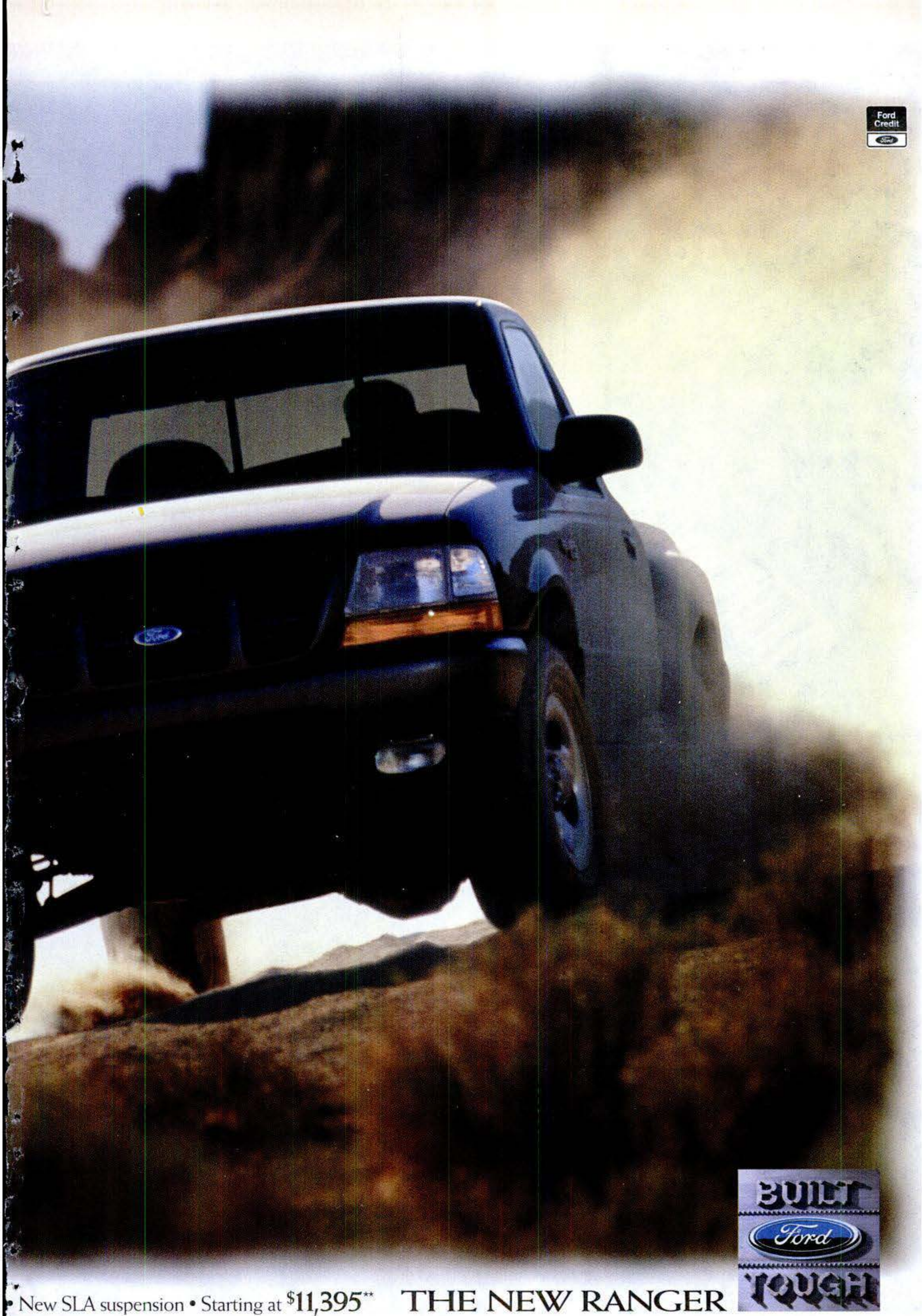

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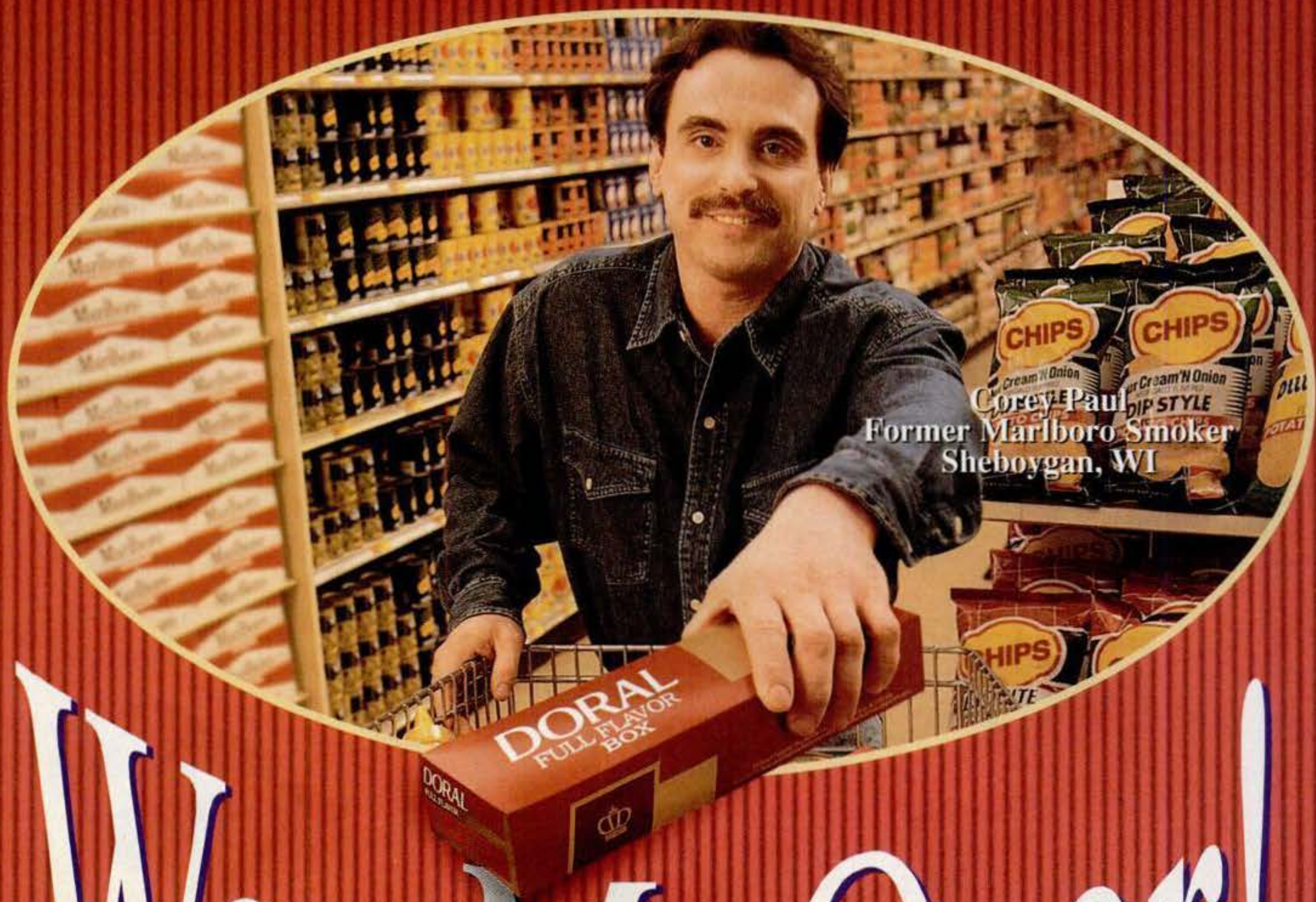

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THE WHAT'S NEW MAGAZINE

Popular Science

MARCH 1998

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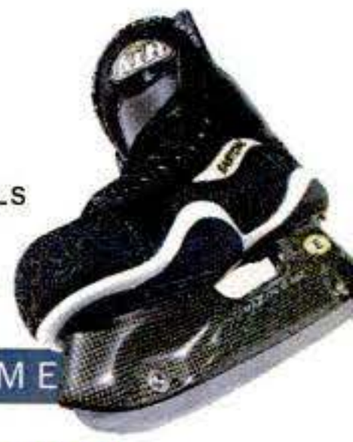
56
Hubble Telescope
Fill 'er up, check the oil: Hubble primes for the future.

COVER ART
DANIELS & DANIELS



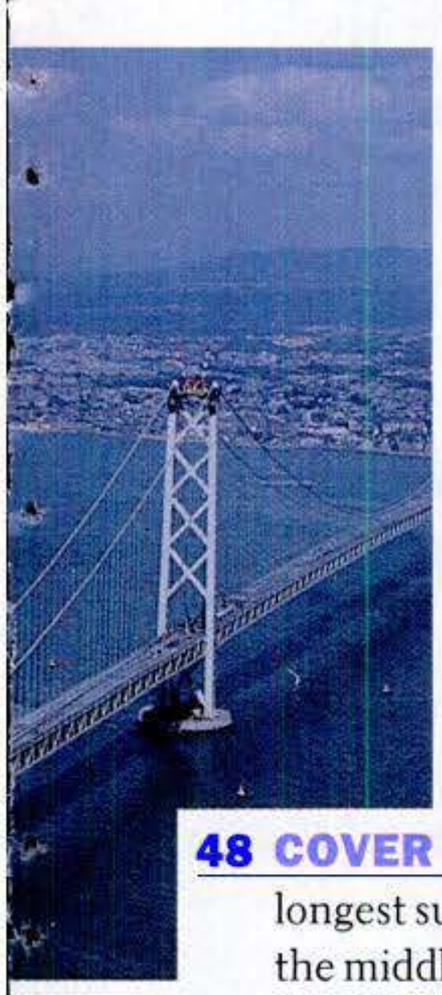
DEPARTMENTS

10 WHAT'S NEW
Comfy hockey skates; covert night light; urban drag racing; Mercedes compacts; Java phone; bridgeless eyeglasses; tiniest 3x zoom camera.

6 LETTERS

79 FYI
How flowering plants know when to bloom; how helicopters work; calories and fat.

92 LOOKING BACK



SCIENCE & TECHNOLOGY

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48 COVER STORY A Bridge So Far The world's longest suspension bridge is opening next month in the middle of an earthquake zone.

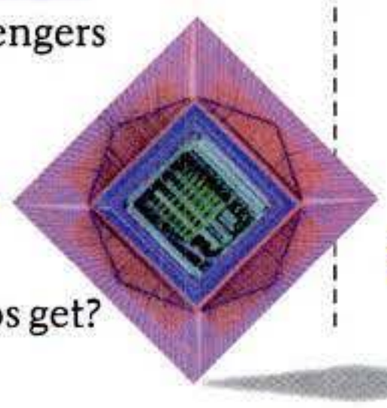
70 Urban Rainforest Leaf by leaf, vine by vine, an African jungle sprouts on New York's west side.

COMPUTERS & SOFTWARE

29 Computers & Software Newsfront Software modems; virtual tax man; inoculating the Net; removable cartridges grow PC storage.

54 Wired Wheels Check your e-mail and get directions while driving, as your passengers browse the Web and watch TV.

64 Computing's Outer Limits As they bump up against laws of physics and economics, how much better can chips get?



AVIATION & SPACE

56 What's Next for Hubble The once-derided telescope will continue its remarkable finds into the next century.

62 A Plane for Land and Sea Agile and stealthy, with plenty of range, France's Rafale may be the most versatile aircraft in the sky.

HOME TECHNOLOGY

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AUTOMOTIVE

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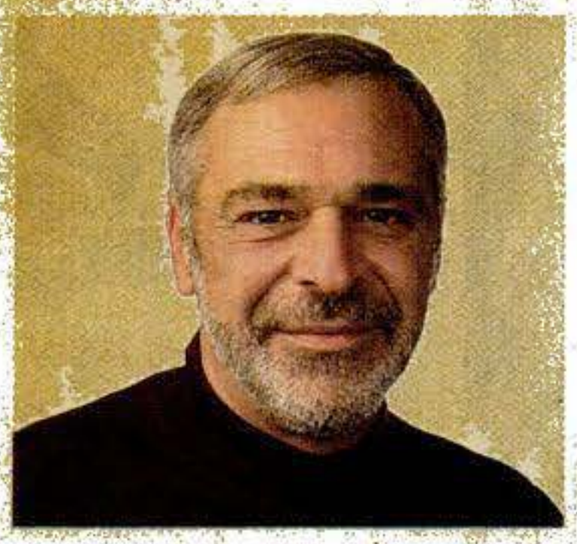
FROM THE EDITOR-IN-CHIEF



Surviving Baptisms of Fire

AS A NATIVE OF BROOKLYN, NEW YORK, I've experienced firsthand two of the great engineering projects of the modern age. I've walked, driven, and bicycled across the 115-year-old Brooklyn Bridge—once the world's longest span—and the Verrazano-Narrows Bridge, still the lengthiest of its type in the United States. Now, however, I'm envying residents of Japan, where the greatest bridge-building project of all time is near completion. With a total span of nearly two and a half miles, the Akashi Kaikyo Bridge will complete a link of Japan's four main islands. Built to resist earthquakes and typhoons, the unfinished bridge weathered an early test when it withstood the Kobe earthquake. Our report takes you step-by-step through the massive engineering feat.

Also surviving a stormy birth, the once-derided Hubble Space Telescope has generated enough amazing celestial data to keep astronomers busy well into the next century. Executive Editor Mariette DiChristina, who has tracked Hubble's progress since its problem-plagued early days, looks ahead to its next decade of work.—*Fred Abatemarco*

Home Automation

YOUR READERS MAY be interested to know that, at least for owners of Macintosh computers, home automation—including voice-activated features—has been available for some time [Home Technology Newsfront, Dec.]. Several companies sell the equipment and software, including Sand Hill Engineering (*www.shed.com*). More information is also available at *web.cs.ualberta.ca/~wade/HyperHome/top.html.*

John Atwell
kermit@chiangmai.a-net.net.th

The Color of Light

CONCERNING YOUR article about the dangers of halogen lamps ["The Light Stuff," Home Technology Newsfront, Oct.], I must say that I am tired of halogen lamps getting a bad rap. We have sold them in our lamp shop for many years and have never had a problem with them. They are good light sources because of the color of light that they produce. Some of our customers with sight problems buy halogen lamps because their doctors have told them that the lights help print show up better when reading.

Stanley Weintraub
Austin, Texas

Supply and Demand

YOUR ARTICLE "Hot Water on Demand" [Home Technology Newsfront, Nov.] would have us buy a pump that circulates cooled-off hot water back to the water heater via the cold water line. For years, we have been told to use only cold water for drinking and cooking, because hot water dissolves more contaminants from pipes. This pump would transport any contaminants dissolved in the hot water line to the cold water line for everyone to drink.

Bruce Keane
b.m.keane@juno.com

While it is true that warm water, because of its temperature, would dissolve more metallic salts than cold water, the U.S. Environmental Protection Agency considers hot and cold water to be potable in every state.

This is because newer pipes, such as those made from polyvinyl chloride, or PVC, leach virtually no contaminants into drinking water. In older homes, however, where copper piping and lead soldering are common, the EPA cautions against consuming both hot and *cold water. For more about common water contaminants in your particular area and how to protect yourself against them, contact your local health department.*

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Measuring Up

HOW CAN IBM'S Thinkpad 770 [Best of What's New, Dec.] have a 14.1-inch screen when its dimensions are 2.2 by 12.3 by 10 inches?

Carol Dunn
carol87@juno.com

The 14.1-inch value refers to diagonal length across the screen.

Pilotless Planes

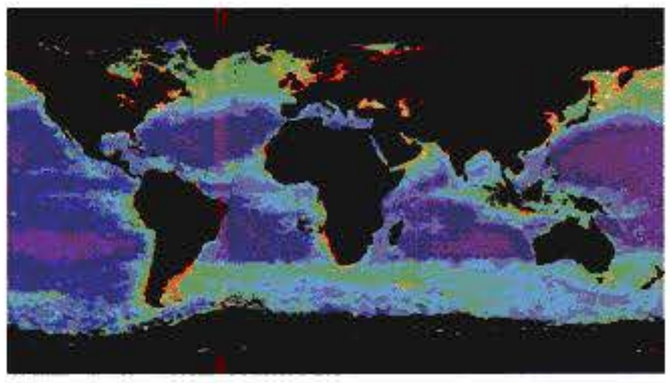
I FOUND YOUR ARTICLE "Fighters Without Pilots" [Nov.] intriguing. However, if the goal is to deliver firepower cheaply, without risk to the pilot, then it seems logical *not* to design a pilotless fighter, but to expand the capabilities of existing guided and cruise missiles. Added range and real-time control of missiles would provide the same capabilities at a fraction of the cost. Once a missile detonates, the remote pilot would then switch over to another missile loitering on the edge of the combat zone, and fly it to the next air or ground target. A similar concept was illustrated nearly 70 years ago in the seminal Buck Rogers book *Armageddon 2419 AD* by Philip Francis Nowlan.

Noel Munson
nmunson@wajones.org

I LOVED YOUR article about unpiloted combat air vehicles. After contemplating their control systems, I thought of two ways an enemy aircraft could disable an entire fleet of these aircraft: either take out the communication satellite or destroy the lead aircraft in the fleet, which would interfere with the control systems of the remaining vehicles.

Brian Kirkpatrick
mrin71.mail@aol.com

Good tactics, but there are ways to deal with both. Satcoms could use constellations of low-flying satellites —with many spacecraft constantly switching message paths—or geostationary satellites. Taking out a constellation requires a series of anti-satellite-weapon engagements, while geostationary satellites are too high to be easily damaged. As for destroying the lead aircraft, all vehicles could perform the "leader" and "wingman" roles. If the leader is shot down, another vehicle would take over.



Correction: The NASA SeaWIFS (Sea-viewing Wide Field of View Sensor) image ("The Color of Chlorophyll," What's New, Jan.) is incorrect. The corrected image above shows the highest concentrations of underwater chlorophyll in red and the lowest in purple.

"Best of What's New" Readers Choice Awards

IN OUR DECEMBER ISSUE, we asked readers to choose their favorite 1997 "Best of What's New" product or technology from our 100 award winners. We're pleased to announce nearly 6,000 of you responded and, with 36 percent of the vote, the HyperSonic Sound speakers from American Technology Corp. took top honors. Producing a pair of ultrasonic signals that are audible only when they hit an object, the speakers provide extraordinary at-home surround sound. A list of the top 10 favorites and voting results is available at *www.popsci.com/bown*.

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WHAT'S NEW

EDITED BY SUZANNE KANTRA KIRSCHNER

Research by Lisa Orkin

Router Converter

WITH ITS 100-piece attachment kit ($59), Ryobi's Multi-Tool is already multitalented. And now it can take on heavier tasks with a $45 router attachment. As a router, the Multi-Tool features a see-through base, edge guide, and dust collector. An optional set of seven ⅛-inch router bits costs $39.
www.ryobi.com

Brighten the Night—Covertly

NIGHT-VISION BINOCULARS enhance available light, but what if there's no light at all? One solution is the Illuminator, a light source that can be seen only with night-vision gear. Its 16-diode array bathes subjects as far as 100 yards away in infrared light. The flashlight operates for as long as 6 hours and is powered by four D-cell batteries. Price: $199. Covert Illumination Technologies, 1801 Royal Lane, Suite 509, Dallas TX 75229.

Downsizing Digital

SHARP'S NEW VE-LC2 digital camera squeezes a big (2.5-inch) bright color LCD screen into a small package—a mere 4.3 by 2.4 by 1.3 inches. The VGA camera also features a 270-degree rotating lens, optical viewfinder, wireless infrared connections, TV output, and 4MB of internal memory for storing as many as 120 pictures. Price: $499.
www.sharp-usa.com

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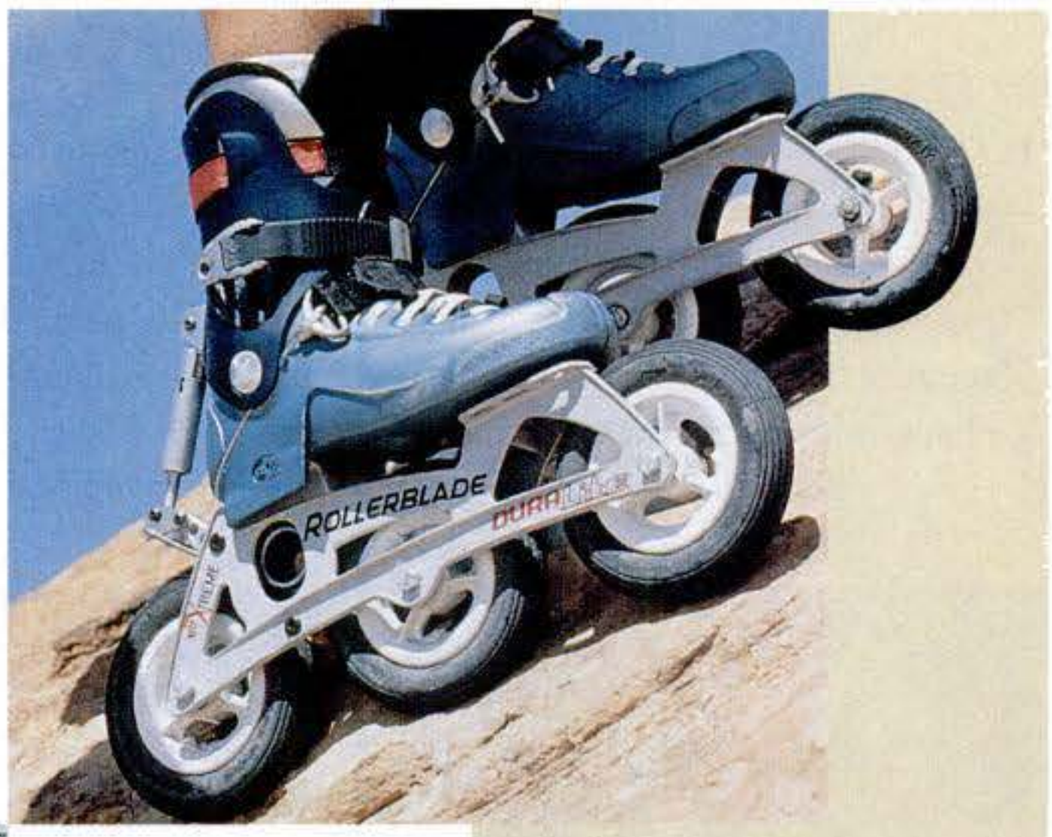
Racing in the Streets

RATHER THAN BUILDING cities, you'll be speeding across the blacktop of 50 prebuilt metropolises in Streets of SimCity, the latest in Maxis' series of simulation games. Your missions range from urban drag-race challenges to undercover spy assignments. You can customize cars and race courses, and even barrel down the boulevards of cities you may have constructed with SimCity 2000. Price: $45, for Windows 95. *www.maxis.com*



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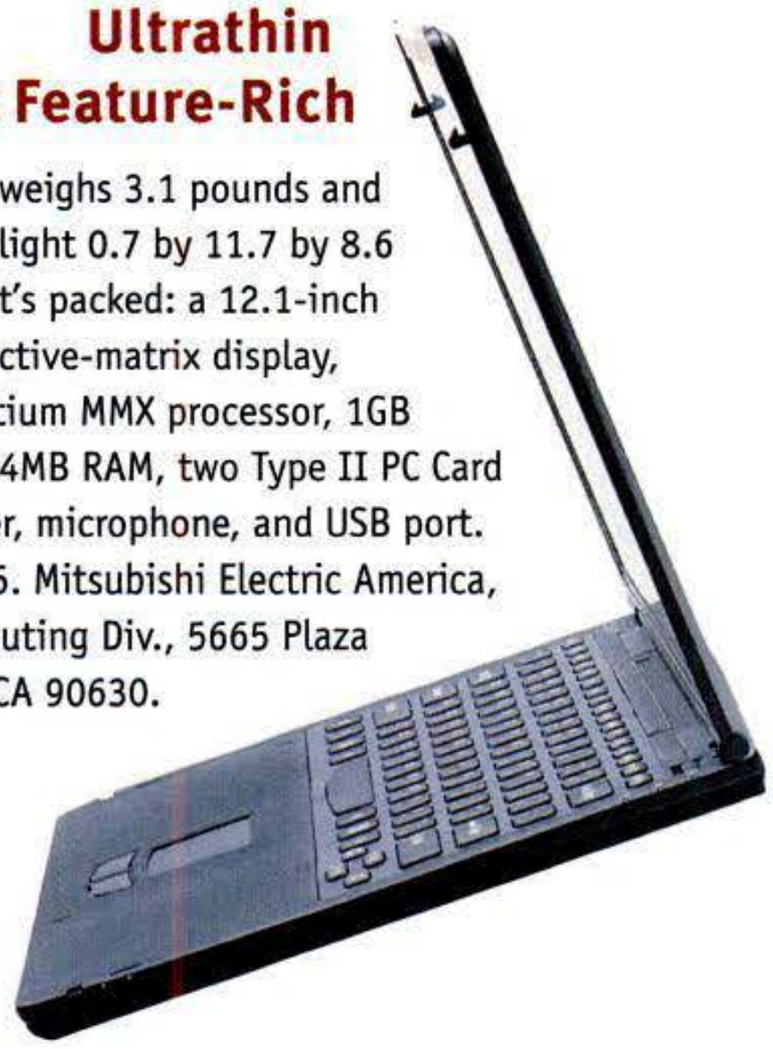
GO OFF-ROAD with Coyote all-terrain inline skates. Their 6-inch pneumatic tires absorb shock. Traditional polyurethane wheels, in comparison, are designed for smooth, hard surfaces. Coyote's brake, located on the right skate, is activated by pressure on the front cuff of the boot; a drum then lowers between the back two wheels, slowing them down. Price: $499. Rollerblade Inc., 5101 Shady Oak Rd., Minnetonka MN 55343.

Ultrathin but Feature-Rich

THE PEDION weighs 3.1 pounds and measures a slight 0.7 by 11.7 by 8.6 inches. But it's packed: a 12.1-inch color SVGA active-matrix display, 233MHz Pentium MMX processor, 1GB hard drive, 64MB RAM, two Type II PC Card slots, speaker, microphone, and USB port. Price: $5,995. Mitsubishi Electric America, Mobile Computing Div., 5665 Plaza Dr., Cypress CA 90630.



Lux Sedan

CHRYSLER'S SPARE-NO-LUXURY approach to full-size luxury cars is expressed in the 1999 LHS sedan. Among the distinctive touches are electroluminescent instrument gauges that mimic watch faces. With a 113-inch wheelbase and 208-inch length, the LHS is the largest of the LH-based sedans. A 253-horsepower 3.5-liter V6 supplies the power. The anticipated base price is about $30,000.

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Kid Talk

LET'S GO READ–An Island Adventure is the first children's CD-ROM with voice recognition. As the child works on reading comprehension, the computer detects whether or not the spoken words match those displayed and provides instant feedback, either audibly or onscreen. A headset with microphone is included. Price: $45, for Windows 95 PCs. Edmark, Box 97021, Redmond WA 98073. *www.edmark.com*

C-Class Notes

MERCEDES 1999 C-Class compact sedans get a facelift, with re-sculpted bumpers, wheel flares, and side sills. Standard equipment now includes side airbags and BabySmart, a detector that deactivates the passenger-side airbag when a made-for-Mercedes child seat is in use. A 2.8-liter 18-valve sohc V6 replaces the inline six that previously powered the C280. Horsepower hasn't changed (194 at 5,800 rpm). Neither has the price: The four-cylinder C230 costs $30,450 and the C280 runs $35,400.

Comfort and Control

EASTON'S Z-AIR SKATES' stiffer carbon-fiber blade holders and ergonomically designed boots give hockey players more comfort and control. Replaceable stainless steel blades can be easily removed for sharpening. The wrap-around outsole prevents medial and lateral foot roll. Foam pads adapt to the foot's position for better ankle support. Price: $400. Easton Sports, 7855 Haskell Ave., Suite 200, Van Nuys CA 91406.

Tiniest of Them All

MEASURING ONLY 3.7 by 2.5 by 1.5 inches and weighing a mere 7.4 ounces, Canon's Elph 370Z is the world's smallest and lightest 3x zoom camera. Its tiny red-eye-reduction flash automatically pops out when you turn the camera on. Advanced Photo System features include mid-roll change. Price: $500. Canon U.S.A., One Canon Plaza, Lake Success NY 11042.

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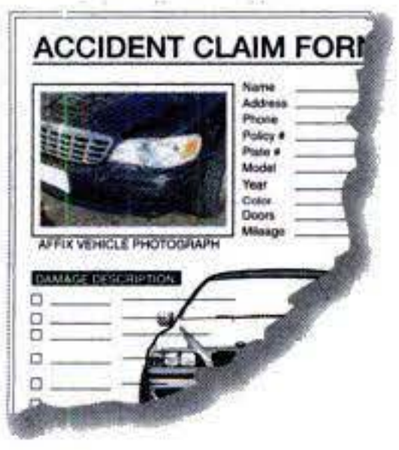

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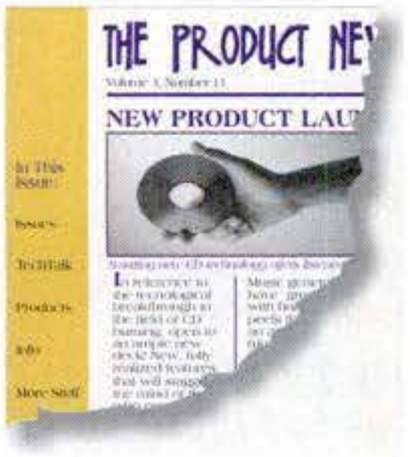

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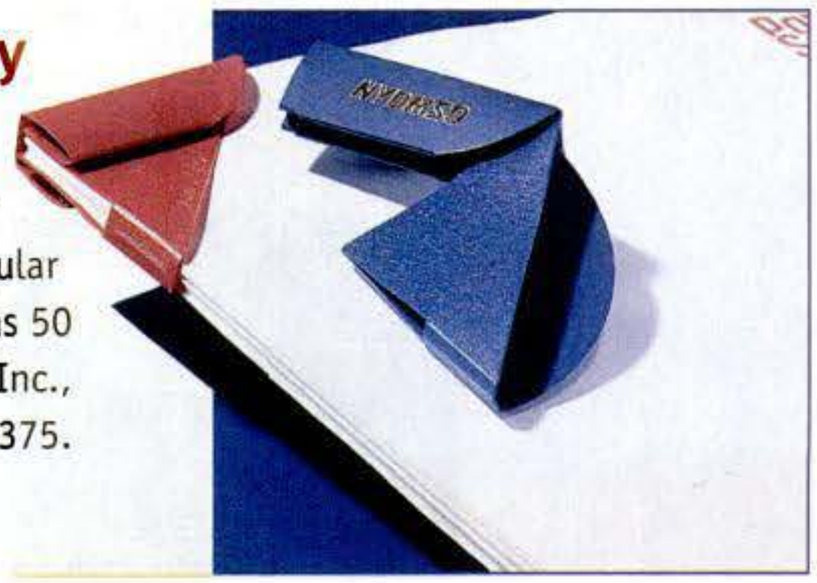

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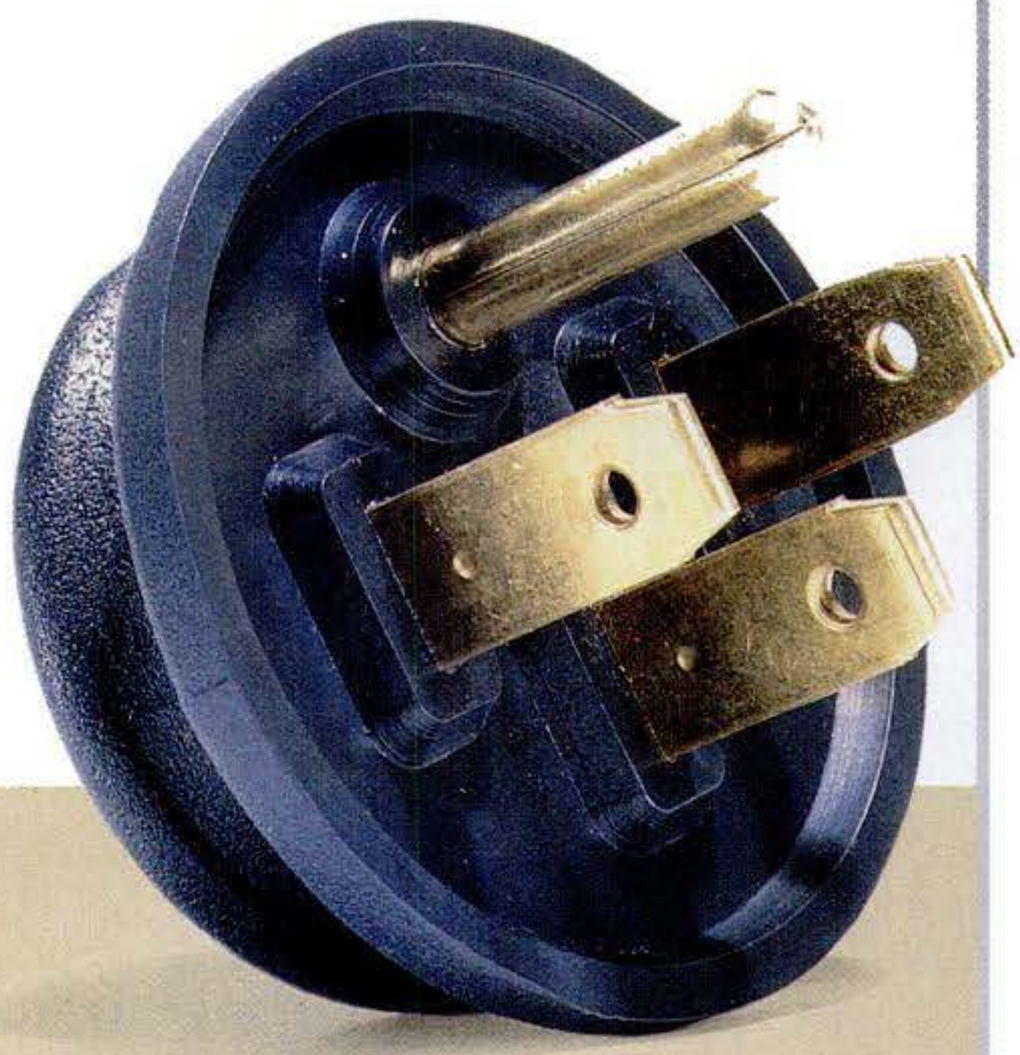
Java Phone

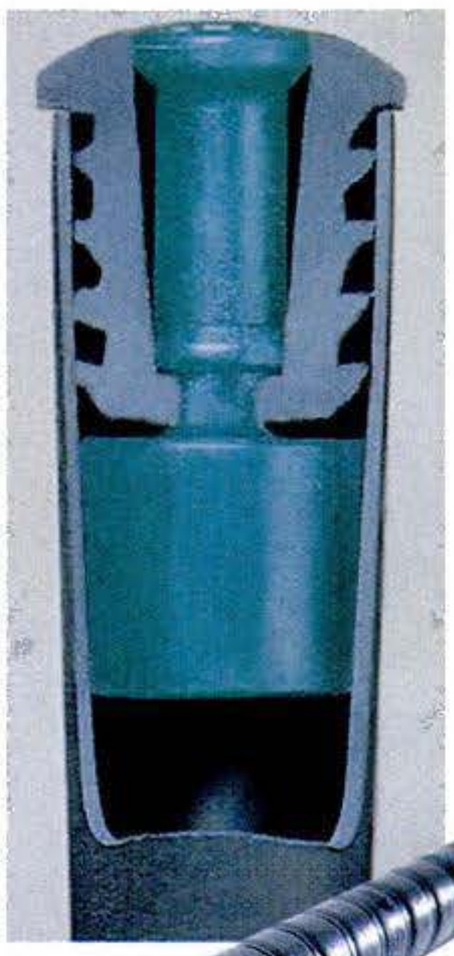
NORTEL'S PROTOTYPE COLOR touchscreen phone lets you access Web pages and services, and send and receive e-mail. The phone will also run small applications that have been created with the Java programming language. The phone should be available late this year. The price is not yet set. *www.nortel.com*



The Switch

REPLACING AN electric range with a gas unit usually means calling an electrician. But not if you have the Noma Power Adapter for gas ranges, a 220- to 110-volt converter. You simply plug your gas range into the converter, and then into your existing electric range outlet. Price: $20. Consumer Gas, Box 650, Carborough Ont., M1K 5E3 Canada.

Shock Stopper



SHOCK AND vibration transmitted through a golf club during a swing can take all the sweetness out of your stroke. Prince's Thunder-Stick irons combat both problems: The Shock Eraser is an elastomer butt cap with a thermoplastic core to absorb impact force. The Cushion Wrap grip, synthetic leather with a felt backing and polyurethane slip-resistant outer coating, provides further protection. Price: $900 for a set of irons. Price Sports Group, One Sportsystem Plaza, Bordentown NJ 08505.

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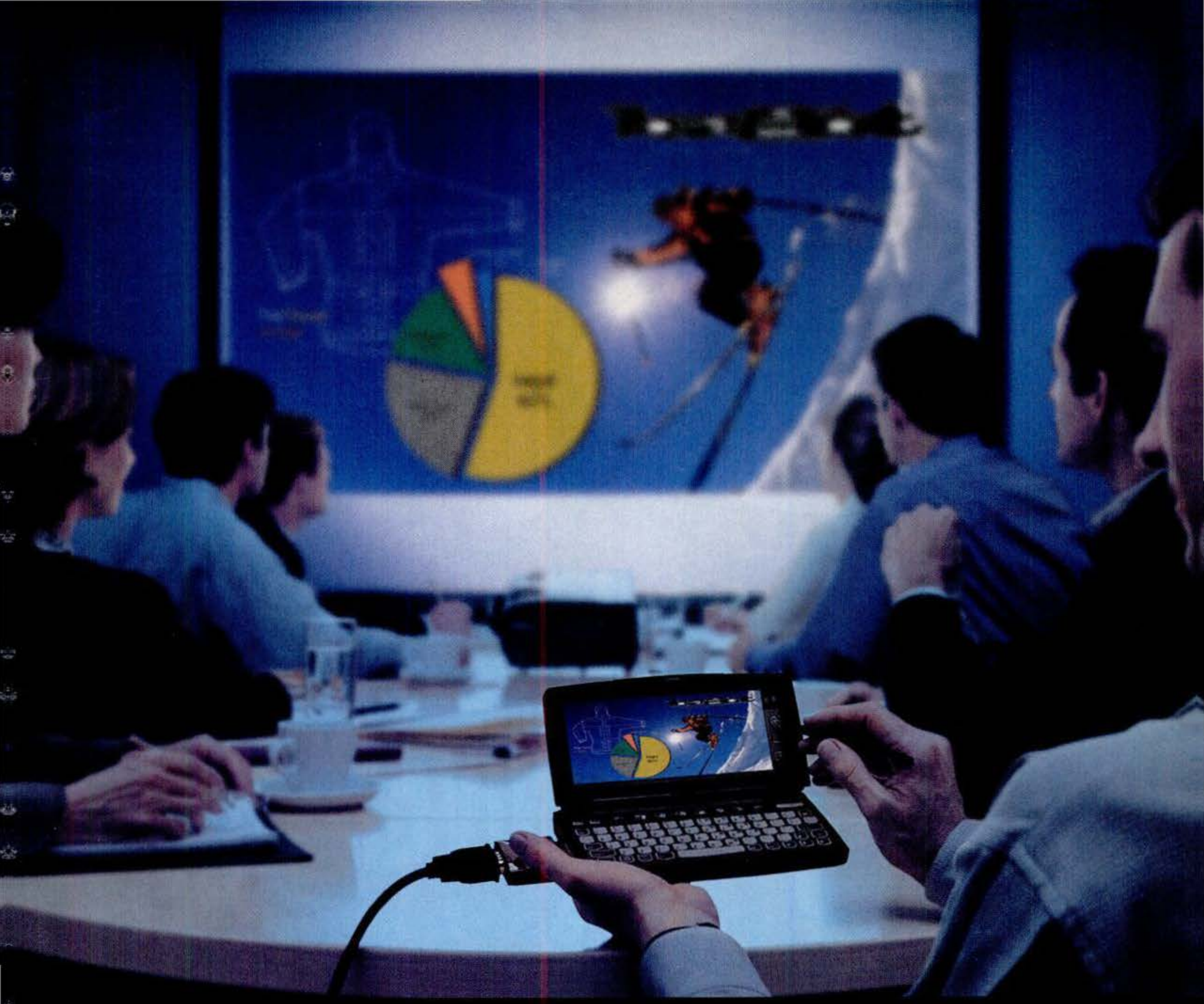

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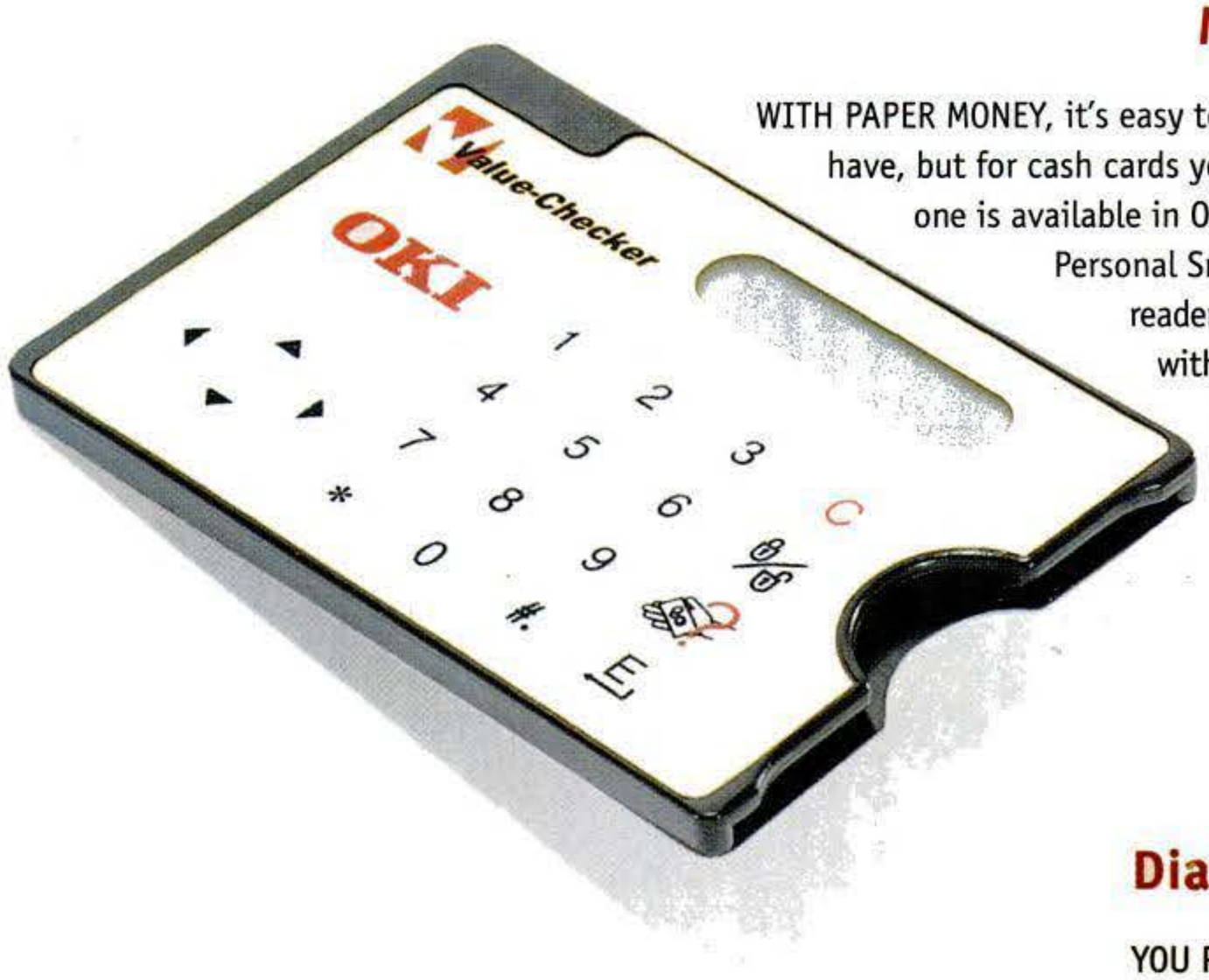

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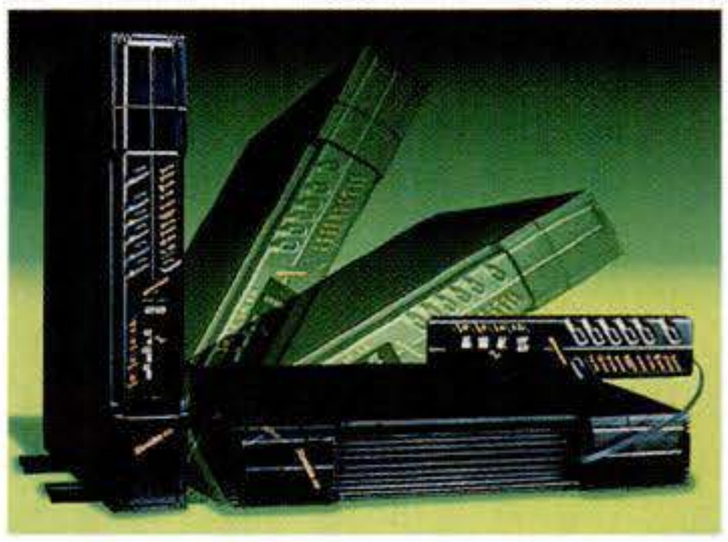

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ATTACH THE BEAVER Mini-Blade to an angle grinder and you've got a punchy power tool that slices through plastic pipes, prunes trees, and carves wood. With a radius of 4⅜ inches, the stainless steel blade fits most 4- and 4½-inch angle grinders. Price: $27. Saw-Tech Industries, 1141 S.E. Grand Blvd., Suite 122, Oklahoma City OK 73129.

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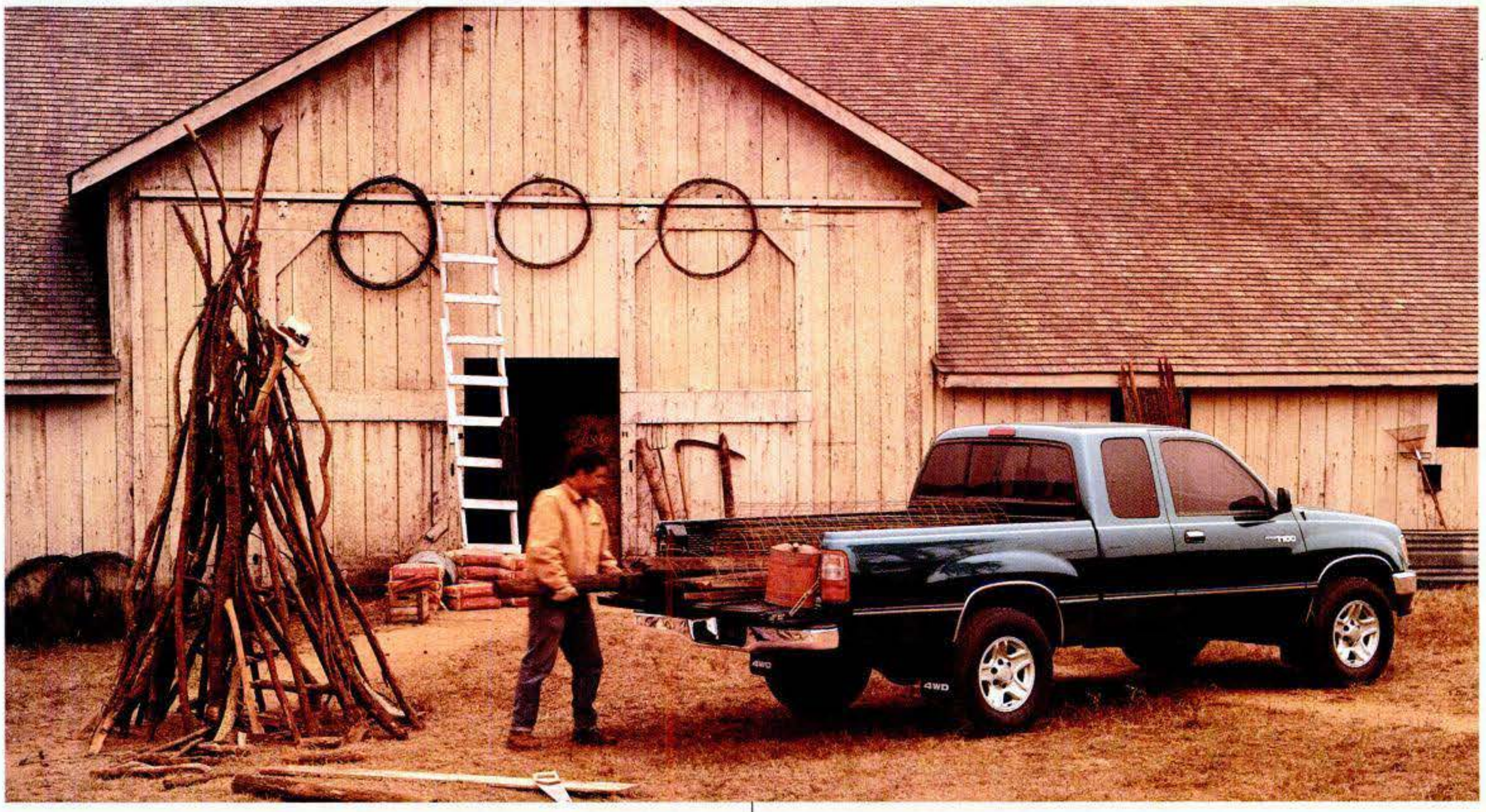

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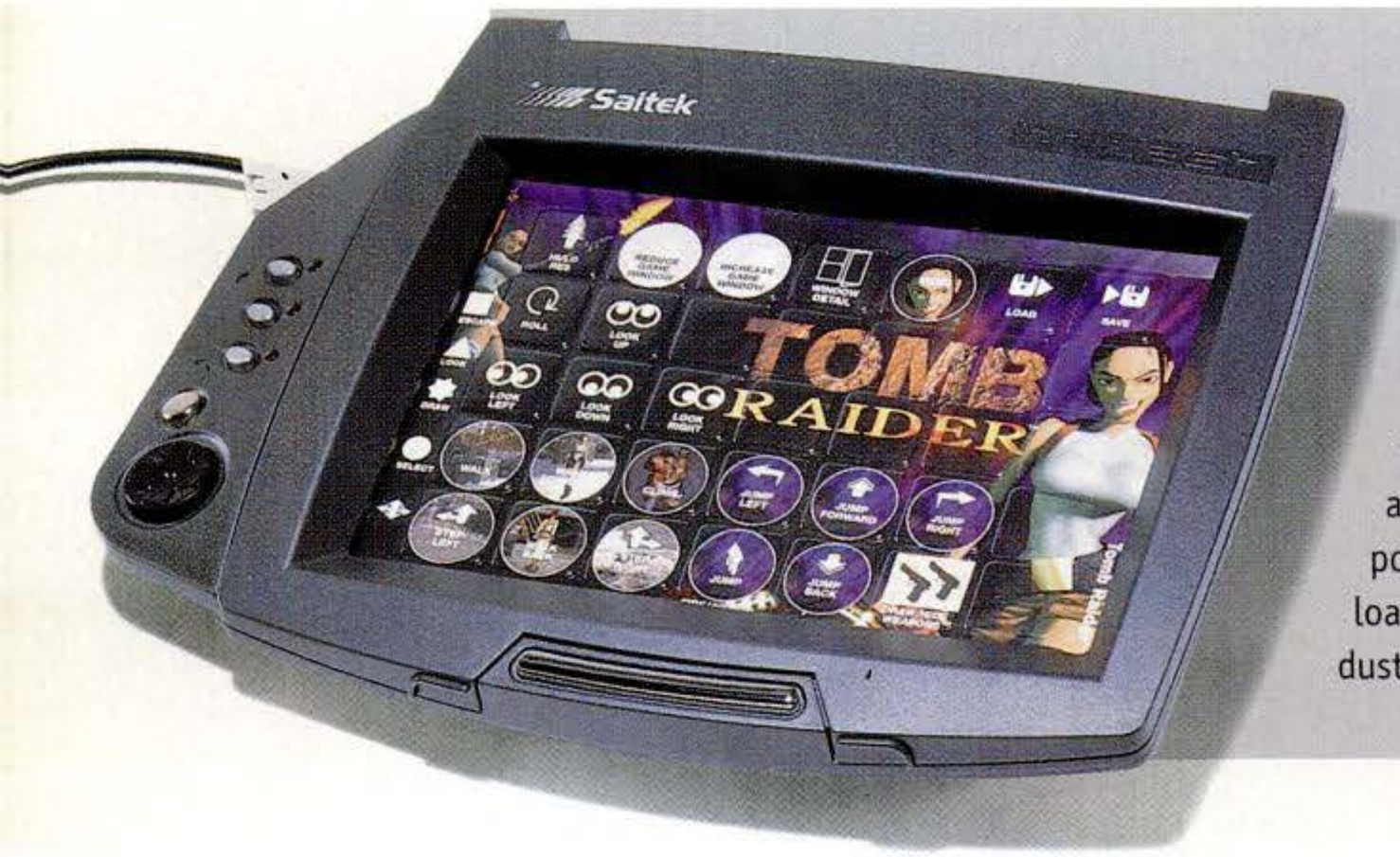

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DO YOU LIKE to use your keyboard when you play games, but can't remember which key does what? The PC Dash touchpad displays the function of each key. Insert a sheet of paper corresponding to the game you want to play, run the bar-code scanner across the top of the sheet, and PC Dash is configured. Sheets provided are for popular games; additional sheets can be downloaded from *www.saitek.com*. Price: $70. Saitek Industries, 2295 Jefferson St., Torrance CA 90501.

Snorkel-Mobile

THE MAXX STEALTH is the first propulsion vehicle for snorklers: It generates 10 pounds of positive buoyancy to help keep them afloat (like a kickboard), or can be adjusted to neutral buoyancy for diving. The unit propels snorkelers at speeds of about 2 mph for more than an hour. Price: $1,195 to $1,995, depending on battery and motor configuration. Mode Industries, 1701 W. Broward Blvd., Ft. Lauderdale FL 33312.

Cards to Go

THE MULTIMEDIA Card, developed by SanDisk and Siemens, is the world's smallest solid-state storage device. Roughly the size of a quarter, it will come in flash and read-only memory versions in capacities up to 10MB, and be used in future cellular phones, pagers, and other handheld products to add such advanced features as storing voice and text messages. *www.sandisk.com*

Power Package

THE 1999 BMW 3 Series sedan shows an evolution that retains most of the lines of BMW's sport sedan. The body is slightly larger, and will be available for the 1999 model year as a 4-door, coupe, and convertible. A new powertrain includes a 168-horsepower 2.5-liter inline six-cylinder engine that replaces the old four. The six is 30 horses more powerful than its predecessor.

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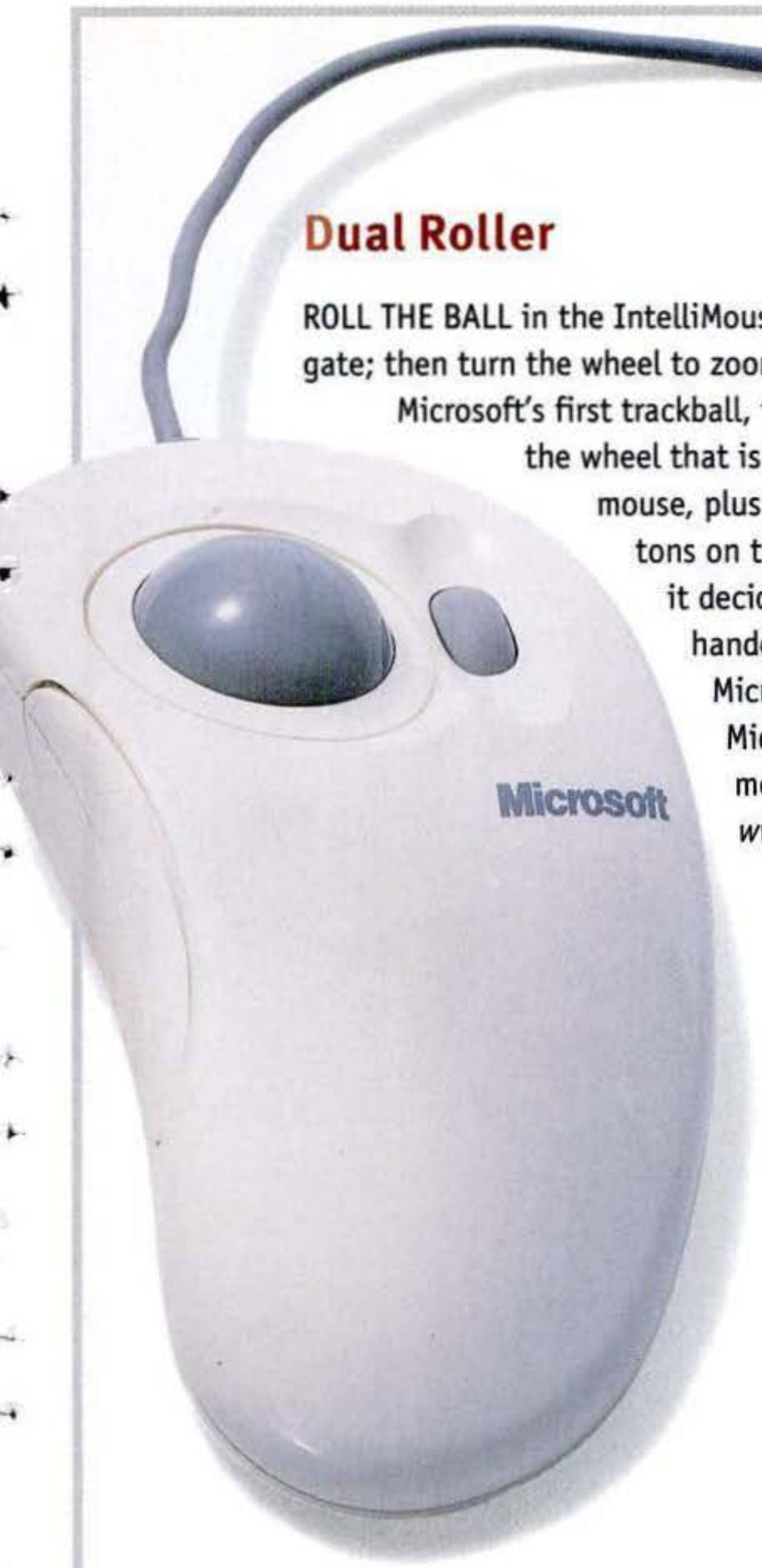
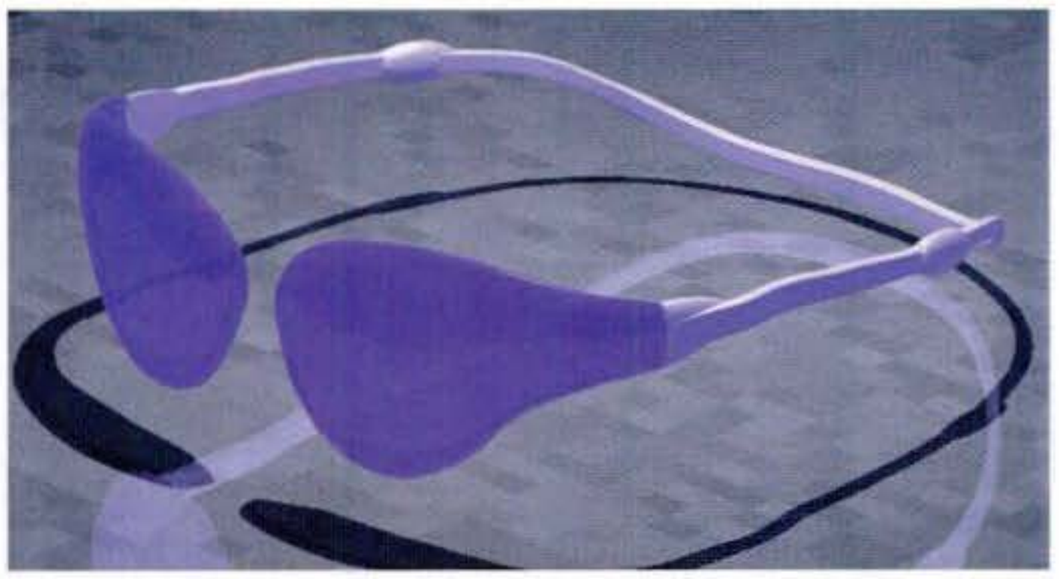
Dual Roller

ROLL THE BALL in the IntelliMouse TrackBall to navigate; then turn the wheel to zoom in on a document. Microsoft's first trackball, the IntelliMouse has the wheel that is on the company's mouse, plus two standard buttons on the left side, making it decidedly for the right-handed. Price: $85. Microsoft Corp., One Microsoft Way, Redmond WA 98052. *www.microsoft.com*





No-Slip Glasses

THE SUHVAN PROTOTYPE bridgeless eyeglasses won't slide out of place. The frames fit snugly at your temples to reduce pressure on your ears and hold the lenses suspended in front of your eyes. The lenses extend to the side to provide better peripheral vision. Suhvan, 555 Main St., E. Greenville PA 18041.

Rot Prevention

MANY VEGETABLES and fruits naturally release ethylene gas, a ripening agent that can accumulate in crisper bins—leading to prematurely rotten produce. Extra Life discs contain zeolite granules coated with potassium permanganate; the two compounds chemically attract ethylene and then oxidize it to render it inert. The discs cost about $4, and last three months. Dennis Green Ltd., 7700 E. Arapahoe Rd., No. 330, Englewood CO 80112.

Bicycle Boat

THE NAUTICRAFT ESCAPE watercraft uses a bicycle-type drivetrain to turn a large efficient propeller, instead of the traditional paddle wheel. This setup increases speed while reducing effort, says the company. The 12-foot craft costs $2,850, or $3,500 when equipped with a convertible top and bilge pump. Nauticraft Corp., 5980 Grand Haven Rd., Muskegon MI 49441.

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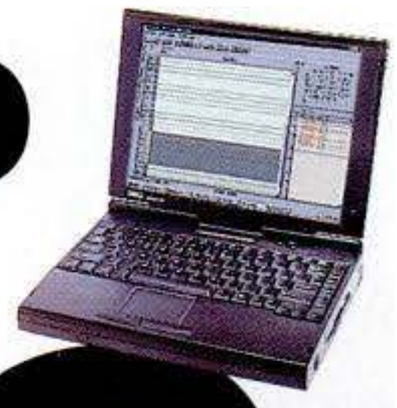

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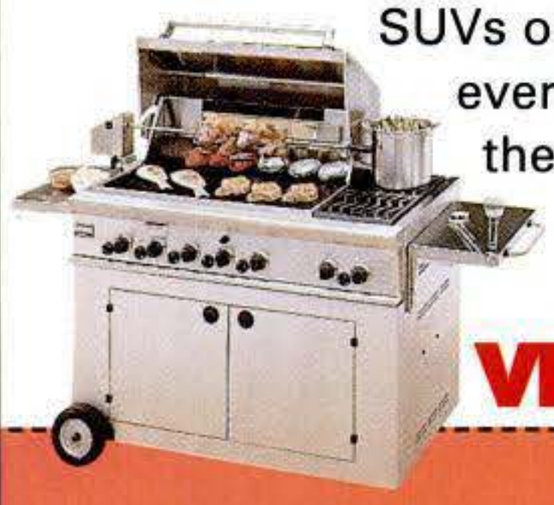

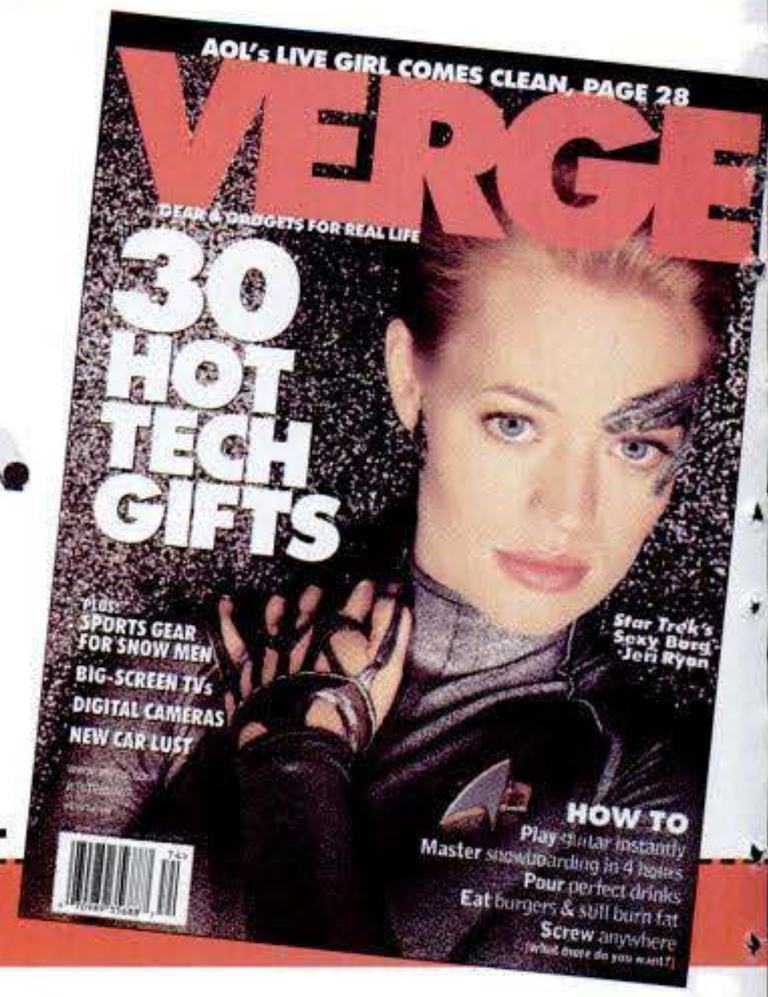

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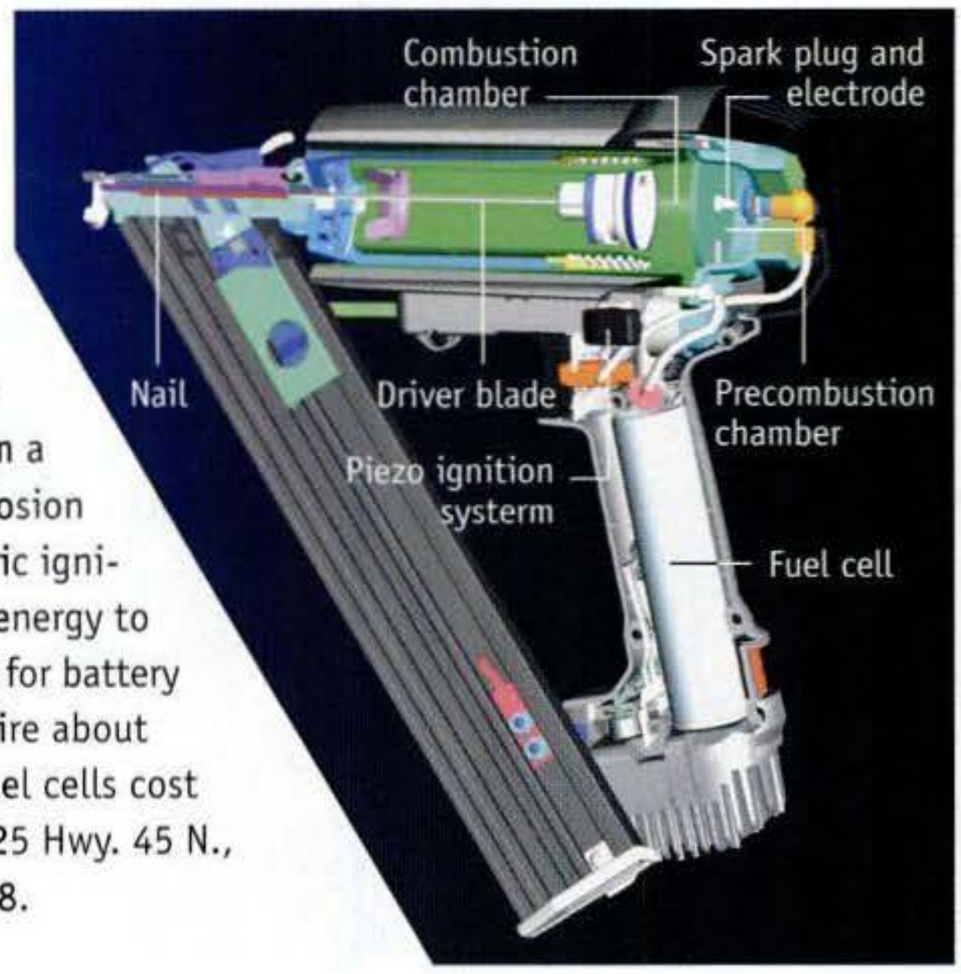
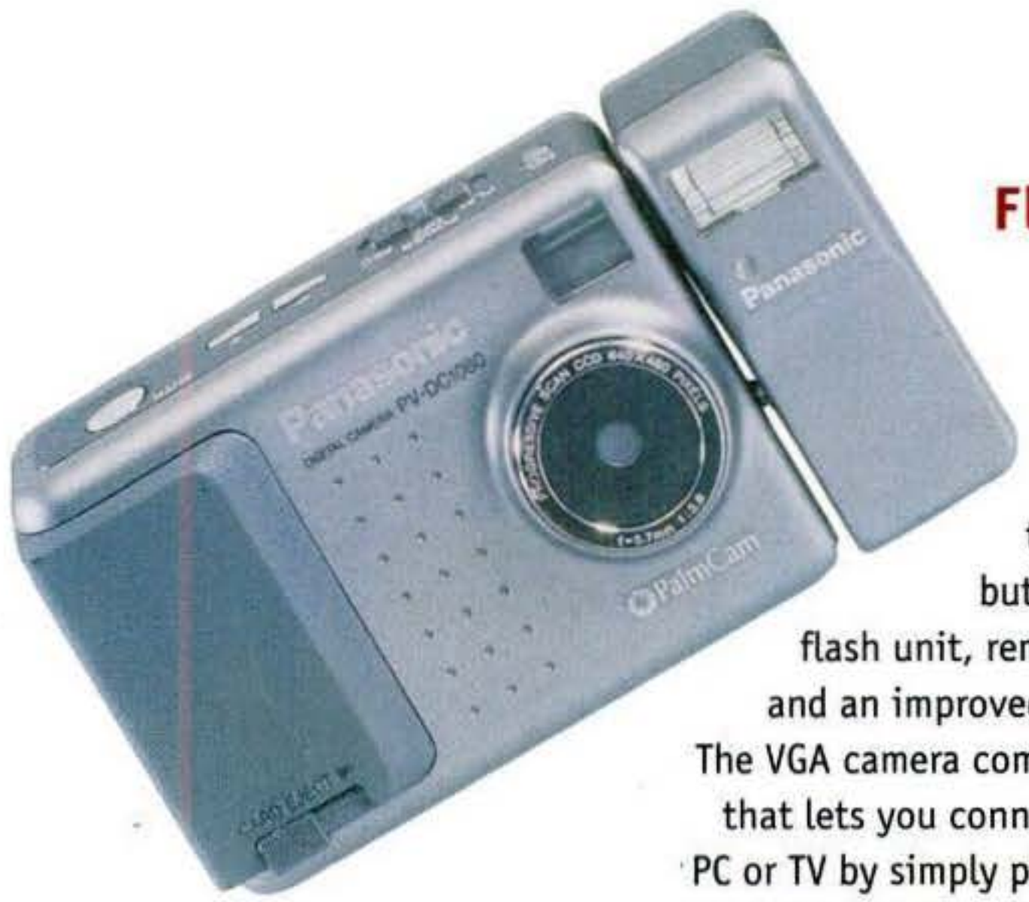
Compressorless Nailing

BAMMER CORDLESS nailers use the same principles found in a car's internal combustion engine: A spark ignites vaporized gas from a fuel cell, which makes a tiny explosion that drives a nail. The piezoelectric ignition, which converts mechanical energy to make a spark, eliminates the need for battery or charger. Each fuel cell should fire about 3,000 nails. Price: about $300; fuel cells cost $7 apiece. Porter-Cable Corp., 4825 Hwy. 45 N., Box 2468, Jackson TN 38302-2468.





Flashier Pocket Camera

PANASONIC'S 5-ounce PalmCam PV-DC1080 digital camera is as tiny as its predecessor, but now has a detachable flash unit, removable memory cards, and an improved color LCD viewfinder. The VGA camera comes with a base station that lets you connect the camera to your PC or TV by simply placing it in the camera cradle. Price: $549. *www.panasonic.com*

Letter Car

CHRYSLER'S 300M sport sedan takes its name from the famed 300-series "letter cars" of the 1950s. The new chassis, however, is based on last year's midsize LH version. While the 300M shares a 113-inch wheelbase with the LH, it is shorter overall at 197.8 inches, partly to avoid the tax penalty large cars are assessed in Europe. Power comes from the all-aluminum 3.5-liter overhead-cam V6, with a smaller engine in cars slated for overseas. Expected price: about $30,000.

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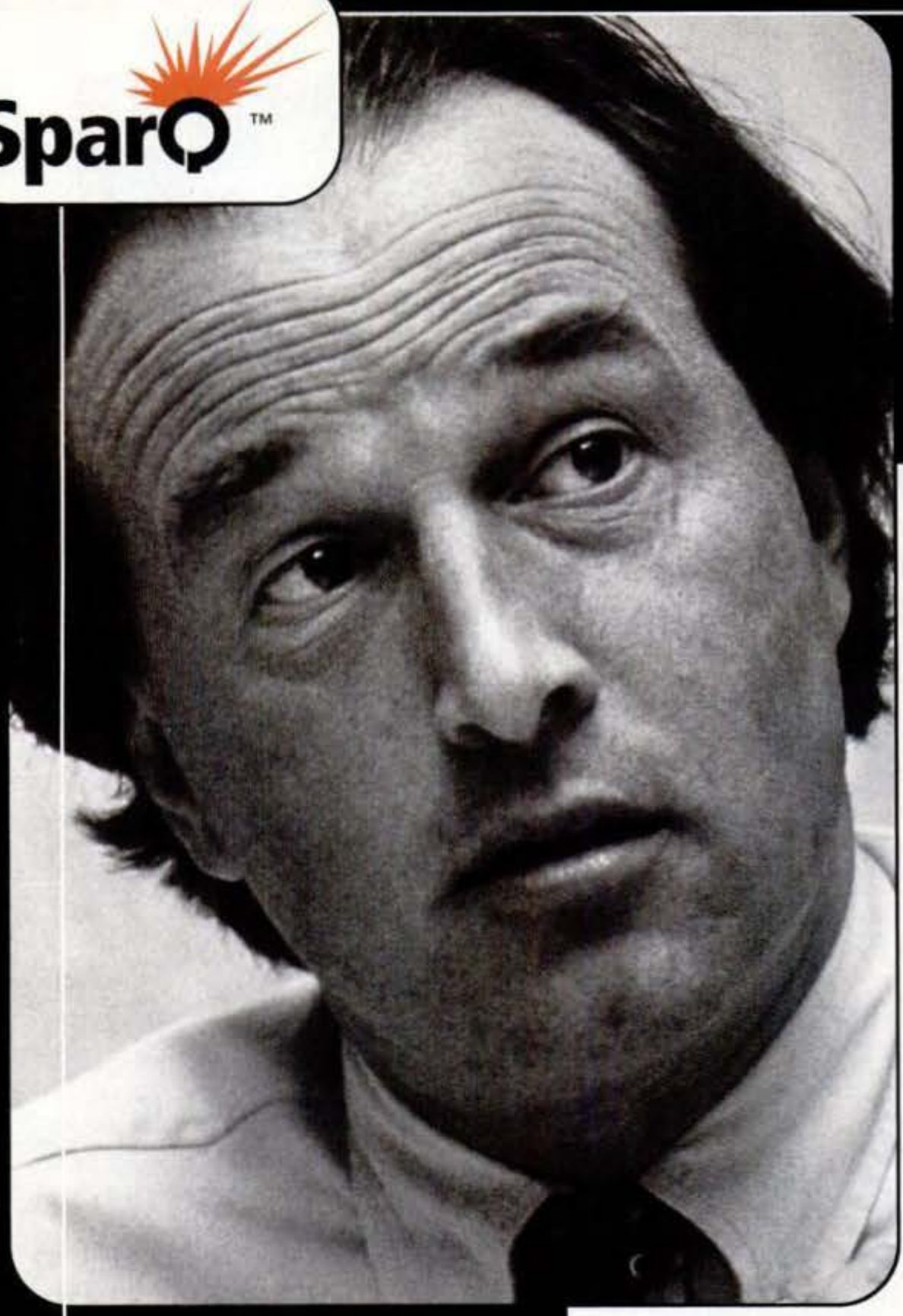

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NEWSFRONTS

SCIENCE & TECHNOLOGY

EDITED BY DAWN STOVER

SPACE

Flying on Mars

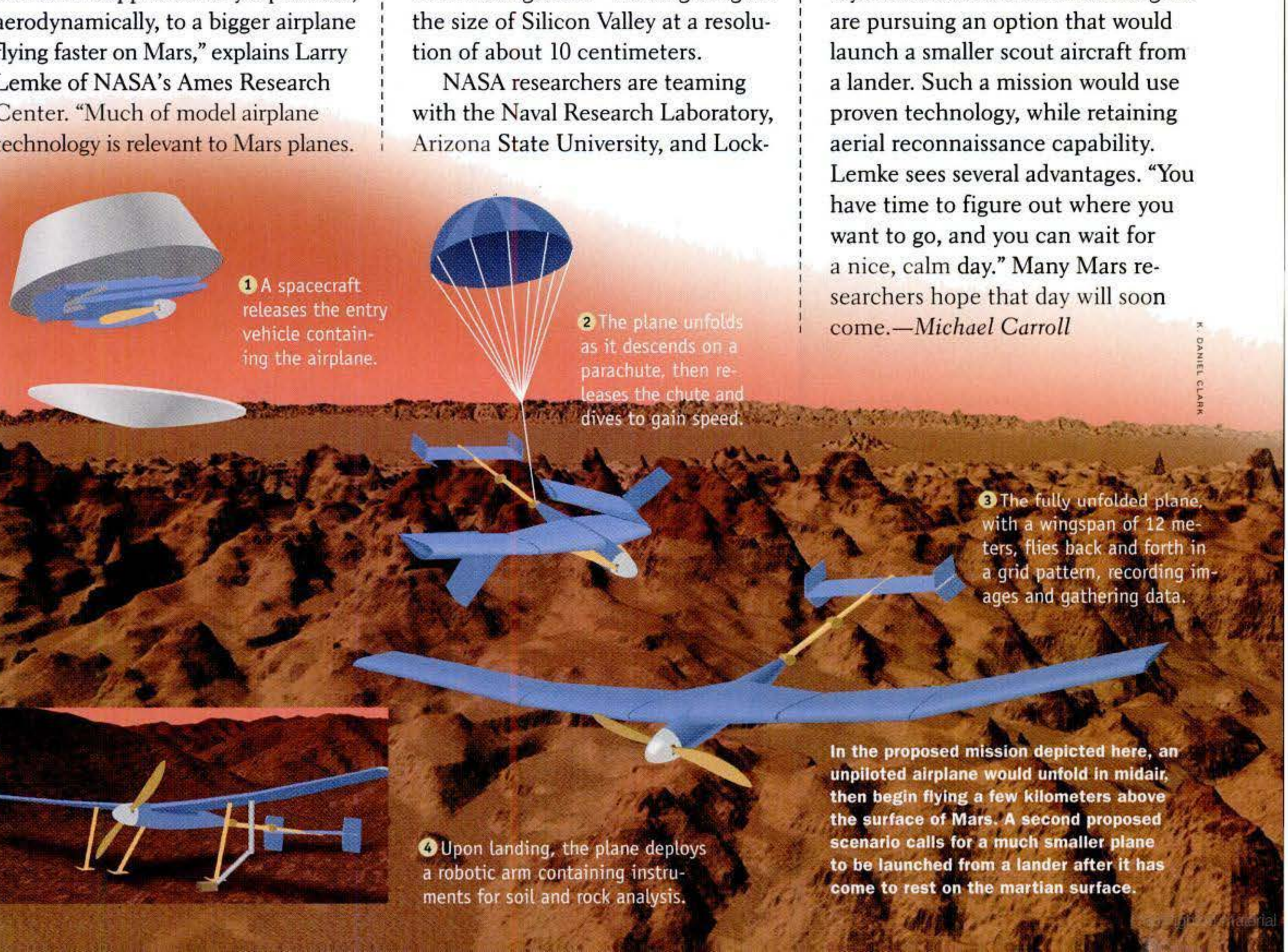
FOR DECADES, hobbyists have sent their radio-controlled model airplanes soaring through the skies, performing spectacular aerobatics. Now, engineers want to take this technology to new heights: the skies of Mars.

"It turns out that a small radio-controlled model flying at low speeds on Earth is approximately equivalent, aerodynamically, to a bigger airplane flying faster on Mars," explains Larry Lemke of NASA's Ames Research Center. "Much of model airplane technology is relevant to Mars planes. In fact, the high-efficiency electric motors we need for Mars can actually be found in a good hobby shop."

Recent successes with the Pathfinder lander and the Mars Global Surveyor orbiter ["Braking for Mars," Feb.] have spurred researchers on to explore the Red Planet in new ways. While Pathfinder viewed a small area in high resolution, and Surveyor will view the whole planet in much lower resolution, a mini-aircraft would cover the middle ground—viewing a region the size of Silicon Valley at a resolution of about 10 centimeters.

NASA researchers are teaming with the Naval Research Laboratory, Arizona State University, and Lockheed Martin Astronautics in a project called Airplane for Mars Exploration, or AME. Initial plans call for the mission to use a Pathfinder-derived protective shell to enter the martian atmosphere. The Mars plane, folded into "an origami-like package," would unfold in midair. An electric-motor-driven propeller would then fly the craft away in the thin martian atmosphere, eventually landing to study the soil with a robotic arm.

So far, NASA has not elected to fund development of the plane. "We got rave reviews on the science, but they basically thought it was riskier than other missions being proposed," says Lemke. So he and his colleagues are pursuing an option that would launch a smaller scout aircraft from a lander. Such a mission would use proven technology, while retaining aerial reconnaissance capability. Lemke sees several advantages. "You have time to figure out where you want to go, and you can wait for a nice, calm day." Many Mars researchers hope that day will soon come.—*Michael Carroll*


1 A spacecraft releases the entry vehicle containing the airplane.
2 The plane unfolds as it descends on a parachute, then releases the chute and dives to gain speed.
3 The fully unfolded plane, with a wingspan of 12 meters, flies back and forth in a grid pattern, recording images and gathering data.
4 Upon landing, the plane deploys a robotic arm containing instruments for soil and rock analysis.

K. DANIEL CLARK

In the proposed mission depicted here, an unpiloted airplane would unfold in midair, then begin flying a few kilometers above the surface of Mars. A second proposed scenario calls for a much smaller plane to be launched from a lander after it has come to rest on the martian surface.

MEDICINE

Tick Talk

A LYME DISEASE vaccine may be on the way, now that scientists at Brookhaven National Laboratory on Long Island have developed a molecular model of a protein found on the surface of Lyme bacteria.

Lyme disease is a bacterial infection spread by deer ticks, which harbor the bacteria in their gut. In 1996, 16,000 cases were reported in the United States. Symptoms range from neurological complications to arthritis and cardiovascular problems. The disease is treated with antibiotics, but often takes months to eradicate.

To determine the structure of the Lyme protein, called OspA, the Brookhaven scientists used X-ray crystallography—a technique in which the protein is crystallized and then bombarded with X rays. As the rays pass through the protein, they diffract and produce a distinctive pattern on film. The scientists analyzed the pattern to determine the molecular structure of the protein. They then used the molecular model to create a synthetic version of the protein.

Deer ticks harbor bacteria that cause Lyme disease.

"Knowing the structure of OspA allows us to create a better vaccine for Lyme disease," says Cathy Lawson of Brookhaven. Patients can be immunized with synthetic OspA, giving their bodies a chance to build up antibodies to the protein. Later, when a tick bites the patient and begins sucking blood, Lyme bacteria in the tick's gut will be exposed to antibodies in the patient's blood. The bacteria will then die, before they have a chance to enter the human host's body.—*Sharon Parmet*

CLIMATE CHANGE

Kickoff in Kyoto

ECONOMISTS AND politicians are debating how consumers and businesses will be affected by the Kyoto Protocol—the international agreement reached in December at the United Nations Climate Change Conference in Kyoto, Japan. But most scientists agree that the protocol is just the beginning of long-term efforts to minimize the human impact on global climate.

The scientific community reached an historic consensus on the issue three years ago when the Intergovernmental Panel on Climate Change—a group of 2,500 scientists brought together by the United Nations to review all available scientific studies—concluded that "the balance of evidence suggests that there is a discernible human influence on the global climate." The panel said that increasing atmospheric concentrations of greenhouse gases, which trap heat and warm the Earth, could boost global temperatures 2°C by 2100, raising sea levels and playing havoc with global weather patterns. But scientists warn that the complexity of the global climate system makes projections about the effects of gas concentrations extremely imprecise.

Under the Kyoto Protocol, developed countries will cut gas emissions by 5.2 percent by 2012. But that won't be enough to prevent a doubling of greenhouse gas concentrations over pre-industrial-era levels by the end of the next century, because greenhouse gases such as carbon dioxide linger in the atmosphere for decades.

The Intergovernmental Panel is planning a new round of studies that will, it is hoped, give a clearer picture of the relationship between greenhouse gases and the climate by 2000 or 2001. In the meantime, panel chairman Robert Watson describes the Kyoto Protocol as "a first step" in mitigating human-induced global climate change.—*Dennis Normile*

ENVIRONMENT

Edible Antifreeze

THREE ENGINEERS at NASA's Ames Research Center have developed a deicing fluid that's good enough to eat. The fluid, which is biodegradable and nontoxic, is so safe that the Food and Drug Administration has approved some of its ingredients for use in food.

The "green goop," officially called the Ames Environmentally Friendly Anti-Icing Fluid, can be used on airplanes, bridges, runways, ships, and cars. It clings to surfaces and forms a barrier against ice. When a plane or car starts moving, the fluid thins out and blows away, so that planes using the deicing agent will have clean wings when they take off. Robert Lockyer, a coinventor of the Ames fluid, says it has the consistency of lime sherbet when first applied, and limeade when the plane is moving.

The anti-icing fluid contains no ethylene glycol, a poison found in other deicing agents. Nor are there any caustic ingredients such as salt, which can corrode metal over time. Instead, the fluid contains propylene glycol, an ingredient of cough medicine and candy bars.

If airports switch to the more enviromentally friendly anti-icing fluid, the spilled portion of the 400 to 1,000 gallons of it used to deice each plane will be collected and recycled, as with today's fluid. Recycling is necessary because the new fluid can harm aquatic wildlife if it makes its way into streams. As it degrades in water, the fluid depletes oxygen.—*S.P.*

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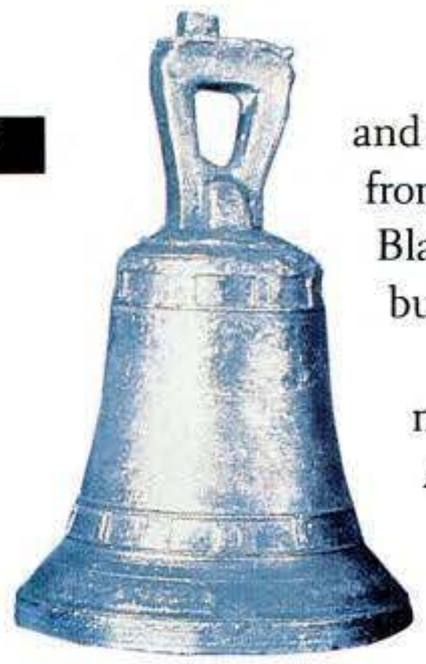
ARCHAEOLOGY

Burial at Sea



Pirate treasure: This bell may have graced Blackbeard's ship.

EDWARD TEACH, better known as the pirate Blackbeard, terrorized the Carolinas and Virginia during the early 18th century. He marauded up and down the seaboard in a converted French merchant ship, the *Queen Anne's Revenge*. In 1718, the 40-gun vessel ran aground during a fierce battle, sinking quickly. The ship has been resting undisturbed in Davy Jones' locker ever since, and would have remained there were it not for the efforts of Intersal, a salvage exploration company. Using an ultrasensitive magnetometer—a sophisticated metal detector—Intersal recently located the ship in 20 feet of murky water near North Carolina's Beaufort Inlet after a decade-long search.

Evidence that the wreck once belonged to Blackbeard is admittedly somewhat circumstantial. But, says North Carolina state archaeologist Steve Claggett, "the ship's bell and much of the hardware is from the right era." And like Blackbeard's, the ship is built of white oak.

One puzzle piece still missing is the pirate ship *Adventure*. As the *Queen Anne's Revenge* wallowed on the edge of a sandbar, Blackbeard called for the smaller *Adventure* to salvage the other ship's cargo. But when the sloop approached, it too hit the treacherous sandbar. Records say the *Adventure* sank "within a gunshot" of the larger ship, but its wreckage hasn't yet been found.

As for pirates' treasure, Claggett does not expect to find gold or jewels. More often, the booty was sugar, rum, and cotton, which were sold on the black market. The real treasure of the *Queen Anne's Revenge* is its historic value. "It's the earliest shipwreck ever found along our coast," Claggett says. "The site is going to tell us an awful lot about early sailing, shipbuilding, and shipboard life for sailors—whether they were pirates or not."—*M.C.*

EVOLUTION

Before Birds Had Wings

BIOLOGISTS NOW have evidence that birds did *not* descend from dinosaurs after all: The embryos of modern birds and reptiles show that their "fingers" evolved differently.

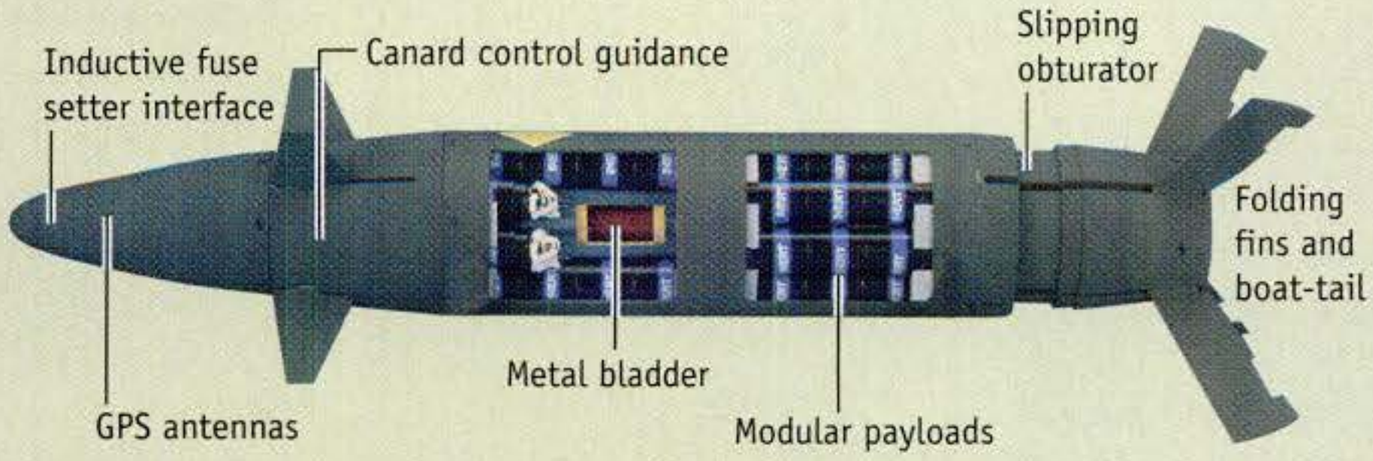
Ann C. Burke, a specialist in the development of organisms, and Alan Feduccia, a leading critic of the dinosaurian bird theory, both of the University of North Carolina at Chapel Hill, analyzed photos of bird and reptile embryos as they developed. Reptile forelimbs had three digits—corresponding to the thumb, index finger, and middle finger of the human hand. Bird wings, in comparison, were developed from digits that match the human index, middle, and ring fingers.

In the contentious world of dinosaur research, the finding has not gone unchallenged: paleontologists Jacques A. Gauthier, of Yale, and Mark Norell, of the American Museum of Natural History in New York City, are already making counterarguments.—*Mariette DiChristina*

MILITARY TECH

Smart Artillery

THANKS TO A new breed of smart shells that can correct their course in mid-flight, the new motto of Army and Navy artillery crews may soon be "one target, one round." Developed by Raytheon TI Systems, the new projectiles are part artillery round, part guided missile.



GPS receivers could enable artillery rounds to change course as they fly toward targets. That would make it possible, for example, to hit enemies hiding behind steep hillsides.

What makes the new rounds so accurate is a GPS receiver that tracks navigation satellites. Target coordinates can be entered by the artillery crew, and corrections can be transmitted mid-flight from surveillance aircraft.

Complementing greater accuracy is an increase in effective range, from the use of a small high-pressure rocket engine. When fired from a 5-inch naval gun, for example, the shell can hit a target about 63 nautical miles away. A standard shell has an accurate range of about 13 nautical miles.

Smart artillery rounds are cheaper than missiles. The cost of each shell (not including its explosive payload) ranges from $5,000 to $20,000, depending upon its size.

The new artillery makes it more difficult for an enemy to backtrace the trajectory to locate the firing gun. Smart rounds are currently being tested as part of the U.S. Navy's Next Generation Naval Gun project.—*Frank Vizard*

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CHEMISTRY

Fallout in the Attic

SCIENTISTS HAVE studied the soil in and around the Nevada Test Site to estimate how much radiation was released during nuclear bomb testing in the 1940s, '50s, and '60s. But James Cizdziel, a chemistry graduate student at the University of Nevada in Las Vegas, wondered how much radiation local residents were exposed to *inside* their houses.

To find out, he collected undisturbed dust from the attics of 45 homes near the Test Site. His analysis showed trace amounts of radioactive cesium and plutonium, but he was unable to determine how much of the radioactive dust entered houses as fallout from bomb tests, and how much blew in later. In any case, the radioactivity is so low that it does not pose a hazard to human health, Cizdziel says.—*D.S.*

CLIMATE CHANGE

Frozen Lab

SCIENTISTS ARE BRAVING sub-zero weather, 24-hour-a-day darkness, and the threat of polar bear attacks to learn more about how the ocean, ice, and atmosphere interact in the Arctic. The project, known as SHEBA (Surface Heat Budget of the Arctic Ocean), will improve forecasts of global climate change.

The centerpiece of the project is a 13-month field experiment that began last October, when a Canadian Coast Guard ice breaker was allowed to freeze into a drifting ice floe about 300 miles north of Alaska's Prudhoe Bay. Scientists are using a variety of instruments on the ship, and in the nearby ice and water, to measure everything from temperature to cloud droplets.

Dick Moritz, director of the project office at the University of Washington, says SHEBA oceanographers have already made one major discovery: In the vicinity of the ship, they found that the salinity of the ocean water was lower than predicted, and the water temperature was unexpectedly high. The scientists think the elevated temperature may have occurred because there was more open water between the ice floes last summer than in previous years. Dark water absorbs sunlight better than white ice floes do. So more water brings more warmth, which in turn causes more melting.

"We're trying to quantify how that process works in nature, and compare that with the way it is simulated in computer models," says Moritz. Improved models will enable scientists to make more accurate predictions of global climate change.—*D.S.*

FISHERIES & OCEANS CANADA

Led by a larger ship, the ice breaker *Des Groseilliers* traveled to the Arctic, where it is now frozen into a large ice floe, enabling scientists to use it as a floating research station (inset).

MEDICINE

Hospital to Go

IT TAKES DAYS or even weeks to set up a portable military hospital like the one in which Hawkeye and Trapper John performed surgery on the TV show "M.A.S.H." But in the near future, setup time may be reduced to a matter of minutes, thanks to the Advanced Surgical Suite for Trauma Casualties, nicknamed the "hospital in a box."

A prototype of this portable hospital, built at the Tennessee-based Oak Ridge Centers for Manufacturing Technology, measures about 5 by 5 by 10 feet, and fits into the Marine Corps' MV-22 Osprey tilt-wing aircraft. From the landing field, the box can be towed to the setup site using two tires and a trailer tongue that are packed inside. Then, in less than 30 minutes, the box can be unfolded to create a fully equipped surgical suite inside a tent with 900 square feet of floor space. The tent holds six patients in air-conditioned comfort for triage and post-operative care at a battle scene, or for humanitarian missions.

To create the folding design, "We borrowed some inspiration from a baby's portable crib," says Ken Chipley, the principal engineer for the project. An early engineering problem with a gaping hinge track in the floor design was solved with a patented three-bar-link hinge design, which can also move laterally.

Aluminum poles and coated-nylon-and-polyester fabric helped keep the tent to only 300 pounds (the total suite weighs 3,000 pounds). Sturdy epoxy-carbon face sheets stiffen the hospital floor and parts of the ceiling, while fiberglass-faced polyethylene composites form the nonstructural parts of the walls.—*M.D.*

Restricted material

COMPUTERS & SOFTWARE

EDITED BY CHRIS O'MALLEY

STORAGE

Gigabytes to Go

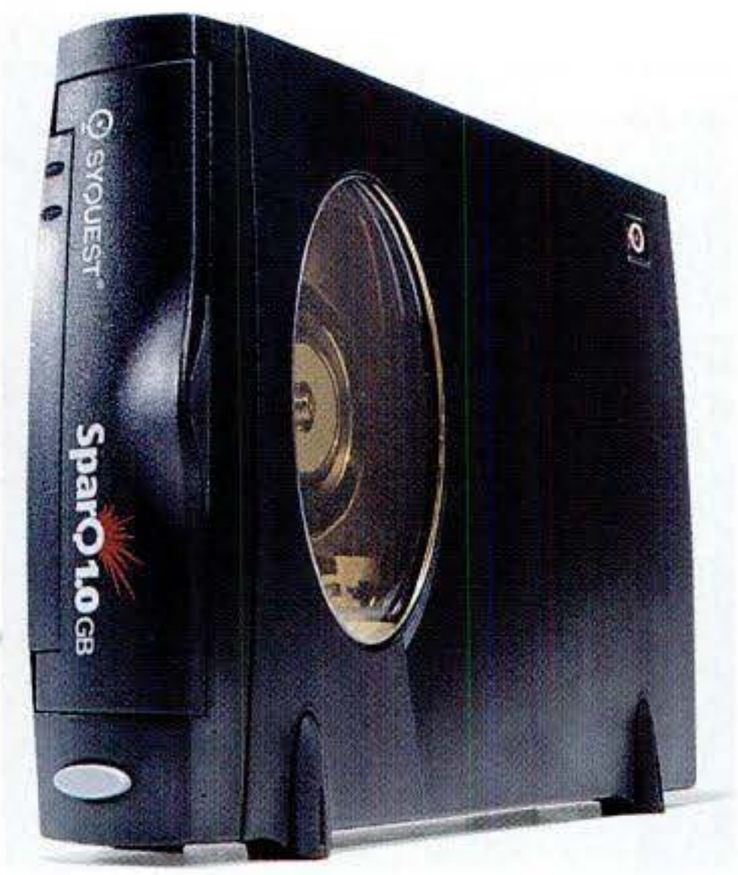
THE NEED for speed is omnipresent, but for millions of PC owners with programs, pictures, and e-mail archives eating up their hard drive space, it's room—not zoom—they urgently need more of. Happily, the choices and sizes in removable-cartridge hard drives are growing, too.

SyQuest's new Sparq 1.0 drive ($199) stores up to a gigabyte per cartridge, and the cartridges cost a mere $39 apiece, or $33 each in a $99 three-pack. In dollars per gig, that's a new low. But the Sparq may not hold that honor for long. A start-up company called Castlewood, run by the original founder of Syquest, has announced a new drive called Orb ($199) that's expected to have 2.1GB cartridges available for $30 apiece. The company is hoping to move its drives into VCRs as well [Electronics Newsfront, this issue]. Iomega, meanwhile, isn't sitting on the success of its 100MB Zip drive. Its new Jaz 2 drive ($549 to $649) can use 2GB cartridges as well as the older 1GB disks from original Jaz drives. The disks cost $149 apiece, however.

All three drives are available in internal and external models. The Orb and Jaz 2 drives work with Windows PCs or Macs. The Sparq drive works only with Windows.—*C.O.*

Iomega's Jaz 2 (left) and Syquest's Sparq (right) drives put gigabytes of storage inside removable, affordable cartridges.

MARCUS ACORD



ONLINE

THERE ARE THOUSANDS of independent Internet service providers in the United States, but a handful of online services have the most customers:

AMERICA ONLINE: **10 million**

INTERNET SERVICE PROVIDERS: **7.5 million**

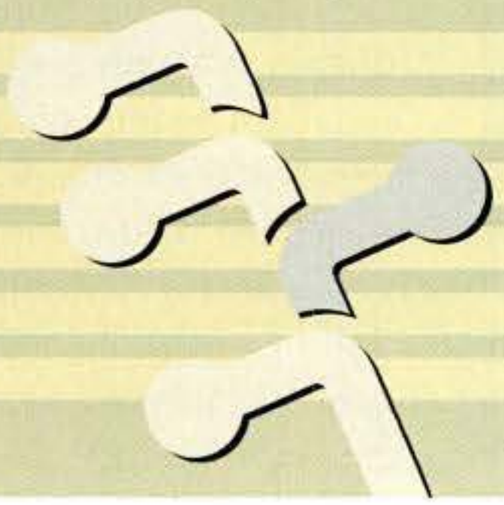
COMPUSERVE: **5.5 million***

MICROSOFT NETWORK: **3.0 million**

PRODIGY: **1.0 million**

OTHERS: **1.0 million**

Source: Cowles/Simba *Pending sale to AOL



INTERNET

Virtual Tax Man

TAX TIME IS looming large, but you don't have to face it alone. The Web provides everything from in-depth explanations of the new 1997 tax laws to instructions on filing your taxes electronically.

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IN TODAY'S ISSUE

TAX PRO'S Corner
News For The Tax Professional

Highlights of Tax Provisions Contained in Balanced Budget Legislation Signed by President Clinton

Don't Know Where To Turn?

Surprised Sailor Finds IRS TaxFax Service Waiting In Every Port

The IRS gives daily tax advice online.

If your first instinct is to turn to the IRS for tax information, you can get that on the Web, too. The IRS Digital Daily (*www.irs.ustreas.gov*) provides answers to tax questions, up-to-the-minute filing information, tax tables, and tax forms, among other services.

Afraid the IRS will turn around and audit you once they're done helping you? *Money* magazine (*pathfinder.com/money/features/auditbait_0196*) has a questionnaire that will predict if you're a likely candidate. And it gives tips on how to avoid being audited.

You can file online with Quicken's TurboTax Online (*www.quicken.com*). It lets you fill out 1040 EZ or 1040 federal forms with limited schedules, as well as California state forms. You can print or file directly to the IRS for less than $10. If you need an expert, the Tax Wizard (*www.taxwizard.com*) will prepare your taxes for you—for a fee, of course. You answer some questions online, and a CPA at the firm of Hargrave and Hargrave will prepare your taxes and mail you a copy of the pertinent forms.
—*Suzanne Kantra Kirschner*

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VOICE RECOGNITION

Memo: Tape to Text

WHAT DO YOU get when you merge a digital voice recorder and conversational speech-recognition software? According to IBM and Olympus, you get a "virtual office"—and probably the next best thing to a traveling assistant with good steno skills.

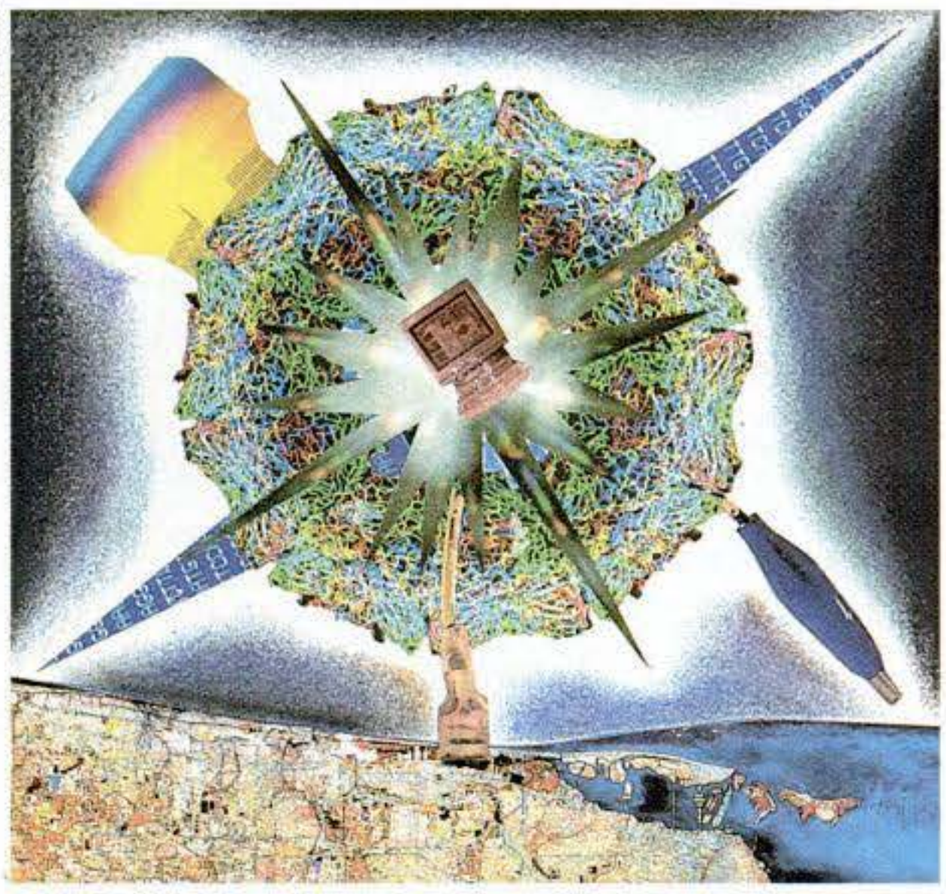
The two companies have teamed up to take voice recognition on the road. Olympus' D1000 digital voice recorder, which records sounds as computer data on flash memory cards, is being paired with IBM's ViaVoice software. ViaVoice, like Dragon's similar NaturallySpeaking software, is a "continuous speech" voice-recognition program that does not require distinct pauses between words. A cable or PC Card adapter will allow you to transfer voice notes from the recorder to a PC and have them automatically transcribed into editable text on the screen.

The yet-to-be-named bundle is expected to cost less than $400 (the recorder alone costs about $250), and the package is slated to be available this month.—*C.O.*

VIRUSES

Inoculating the Net

MORE THAN 14,000 computer viruses are known to exist, and new ones are being reported at the rate of six to eight a day. And an epidemic can spread quickly in our wired world from uploading and downloading infected files. But the Internet's long arms may provide a solution, too.

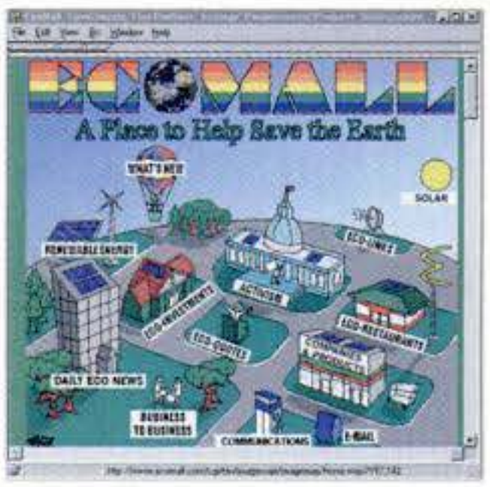


CATHERINE PARR

Back in 1991, when a virus was more likely to spread via floppy disk, scientists at IBM's T.J. Watson Research Center in Yorktown Heights, New York, began working on a system that could use the Internet to detect and eradicate a virus on a computer anywhere in the world—without direct human intervention. Using neural network and expert system technologies, the scientists succeeded in creating what they're calling an Immune System for Cyberspace. The system works this way: A computer in a local area network detects some programming code or a file that might contain a virus. It sends a copy to an "administrator" PC, which in turn forwards it over the Internet to an IBM analysis lab. The automated lab verifies that the sample contains a virus, extracts a signature to identify the virus, figures out how the virus infects other computers, and sends a prescription back to the administrator PC, which disinfects the PC with the virus.

It can be a quick fix. A new virus can be found in Albania, and computers in Tokyo can be immunized against it a few minutes later, according to Steve White, the project's senior manager. The recently patented software might be turned into a commercial product later in 1998.—*Michael Antonoff*

WEB WATCH



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Old Ireland
www.ireland.org
Photographic images of an Ireland gone by, with repros for sale.

Emeril Legasse
starchefs.com/elagasse.html
The man, the chef, the recipes, the book, the restaurant.

Home Recording Rights Coalition
www.hrrc.org
Tapers unite to learn about and defend their reproducing rights.

Net Insider Profiles
www.netinsider.com/audio
Audio clips of interviews with Internet movers and shakers.

QTVR World
www.qtvrworld.com
360-degree images from around the world.

U.S. Lawnmower Racing Association
www.letsmow.com/uslmra
Riding mowers step on the gas while cutting the grass.

—Suzanne Kantra Kirschner

Restricted material

R & D

Natural Computing

WHEN PEOPLE communicate with other people, they frequently speak, point, gesture, nod, and maybe walk around the room while doing so. When people communicate with computers, they usually tap on a keyboard and maybe push a mouse. Makes you wish computers were more like people, doesn't it?

That's precisely the wish—and quest—of Mark Lucente. An IBM researcher specializing in human-computer interaction, he's developed a prototype of tomorrow's "multimodal" user interface. Essentially, Lucente's experimental interface attempts to mimic human senses like sight (with an embedded camera) and hearing (with voice-recognition software), and interpret intelligently what it senses with special software algorithms to foster better person-to-computer communication.

In a recent demonstration, Lucente asked a computer with a wall-sized display to "give me the world." An image of Earth appeared. He then opened his arms about 2 feet apart and asked the computer to "make it this big." The Earth image quickly enlarged to roughly the diameter between his hands. Next, he pointed and asked the computer to "move it over there," whereupon the image moved in the direction of his finger. The appearance of such images can change or adapt depending on where the user is standing, too.

Lucente says the interface he envisions may be 15 years away from practicality, and even simple tasks like the ones he demonstrates require far more computing power than today's PCs possess. But Lucente thinks a more human-like approach is already overdue. "The PC is really just a typewriter shoved under a television screen," he says.—*C.O.*

CHIPS

Soft Hardware

THE LATEST TREND in computer hardware? It's going soft—as in software that can handle tasks normally performed by hardware components.

Motorola recently demonstrated new "software modem" technology that will soon enable computer makers to build systems that have 56Kbps modems, yet don't have all of the usual modem data-pumping hardware. Rather, the data-control and -pumping functions are directed by the software and executed by the PC's microprocessor.

Zoran Corp. has its sights set on the video and audio decoders that accompany DVD-ROM drives. Its SoftDVD movie player works with Intel MMX processors to play the MPEG-2 digital video and Dolby Digital (AC-3) surround sound encoded on DVD discs.—*C.O.*

PC-TV

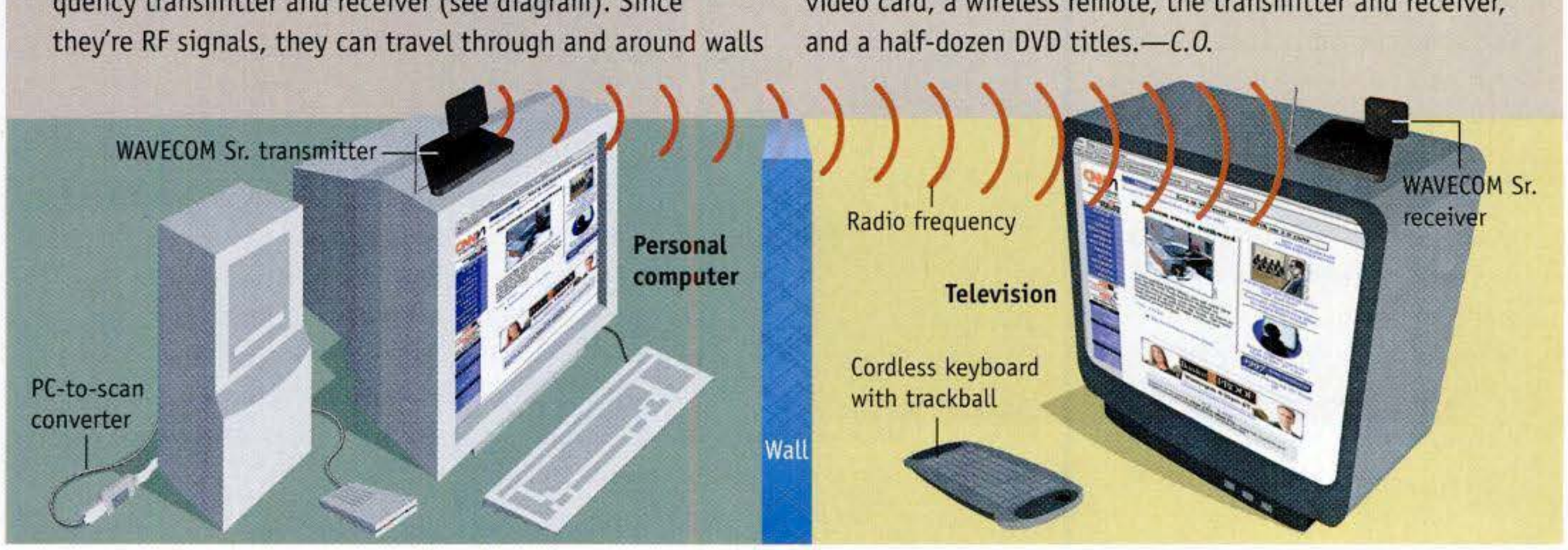
A Wireless Marriage

YOU'VE GOT A hot new PC with a high-speed modem and a DVD-ROM drive in your home office. So do you really need a WebTV box or a DVD player in your living room? Maybe not, thanks to some clever new wireless systems.

RF-Link Technology's new Wireless PC@TV extends your Internet reach from a PC in one room to a TV in another. It uses a scan converter to translate your PC's video display signals into signals that a TV can display, and wirelessly sends the audio and video signals to a TV using a radio-frequency transmitter and receiver (see diagram). Since they're RF signals, they can travel through and around walls and other obstacles—up to about 100 feet. A wireless keyboard lets you control your PC from the TV room, and special browsing software makes Web pages easier to read on the TV. At $599, it's roughly twice the cost of a set-top WebTV receiver, but you can use your regular Internet service provider and printer.

Hi-Val's DVD Home Entertainment System actually uses the same RF transmitter and receiver as the Wireless PC@TV, but pairs them with a DVD-ROM drive to let you play DVD movies on your PC and broadcast the audio and video to your TV. The $849 system includes the DVD drive, a MPEG-2 video card, a wireless remote, the transmitter and receiver, and a half-dozen DVD titles.—*C.O.*

ALEX REARDON



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ELECTRONICS

EDITED BY FRANK VIZARD

VIDEO

Camera in the Round

IMAGINE PREVIEWING a golf outing by logging onto a Internet site to stroll around the links. Or how about visiting a resort to get a peek of your room and the surrounding grounds. Virtual visits to destinations may soon be commonplace, thanks to a camera that makes filming a 360-degree environment much easier than before.

The Be Here panoramic camera takes a 360-degree picture in one shot. Software converts the circular picture into a viewable image on the Internet.

No more stitching pieces of film to re-create a total environment: The Be Here Portal S1 panoramic lens by Be Here of San Jose, California, can capture an entire area in one shot. The lens, which can be attached to either a 35mm or digital camera, photographs not only everything within a 360-degree range, but also the sky above. That's not all: Foreground objects within a 50-degree range are captured as well. Images are initially rendered as a doughnut-shaped picture, but Be Here's computer software quickly transforms that picture into a panorama.

Once the image is converted, you have full control over what's being viewed. A zoom feature lets you focus on a particular area. And a series of images can be linked, for a sensation of movement from one space to another. You control the viewable space, so you see through your own eyes, rather than a cameraman's.

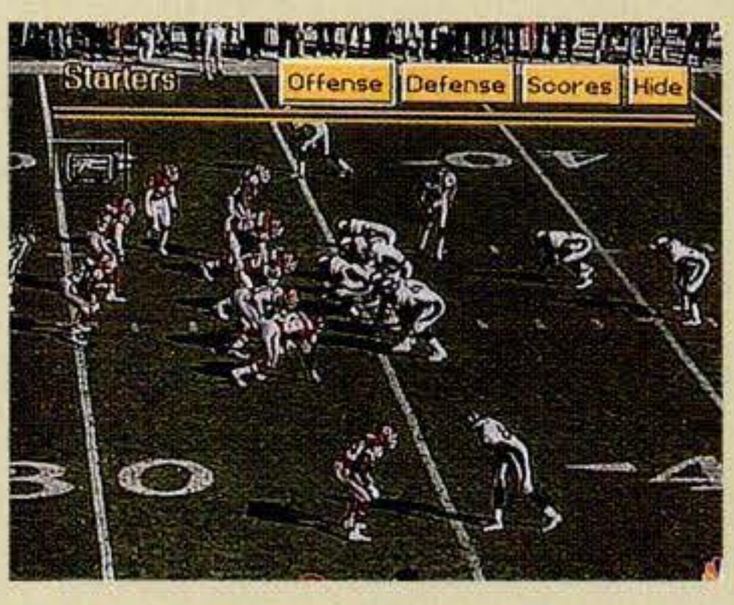
The camera costs about $10,000, so its initial use may be limited. The company, meanwhile, is developing a live-video version with the same features as the still picture lens. Such a camera would prove handy for TV news organizations looking to increase traffic on their Web sites, for example. Be Here estimates that the live-video model will be available early this year.—*F.V.*

TELEVISION

Going Interactive

TV SETS WILL ACHIEVE a new degree of interactivity next fall with the introduction of a technology called Wink, scheduled to appear first on Toshiba models. Wink allows graphics and other data to be broadcast via the vertical blanking interval, which is sometimes viewable as the black bar between video frames. TV viewers can access the extra information by clicking on an onscreen "I" icon.

NBC will be the first broadcaster to transmit Wink data. NFL football games and the "Tonight Show" are expected to be among the first programs to utilize Wink. ESPN and TNT have signed on as well. Trivia quizzes, sports statistics, news, weather, and viewer polls will be featured via Wink. Football fans, for example, could access a team's offensive and defensive rosters or check on other scores around the league, using their remote control as a pointer. The new television sets will include modems that will allow program watchers to respond via telephone lines. Wink may also be soon employed by cable television systems in much the same manner.



Wink offers television viewers interactivity.

Wink may appeal to advertisers, since viewers will be able to interact with commercials. With Wink, you could purchase a product on the spot, ask for brochures or free samples, or request money-saving coupons simply by pushing a button on your remote control.

Wink already is available in Japan and is included in TVs made by JVC, Panasonic, and Sony. If Wink catches on there, it's likely these manufacturers will include Wink in their U.S. products.—*F.V.*

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VIDEO

Record on a Disc

YOUR NEXT VIDEO recorder might not use magnetic tape at all. The newest wrinkle in video recording is called M-DVD, and it soon may appear at a store near you.

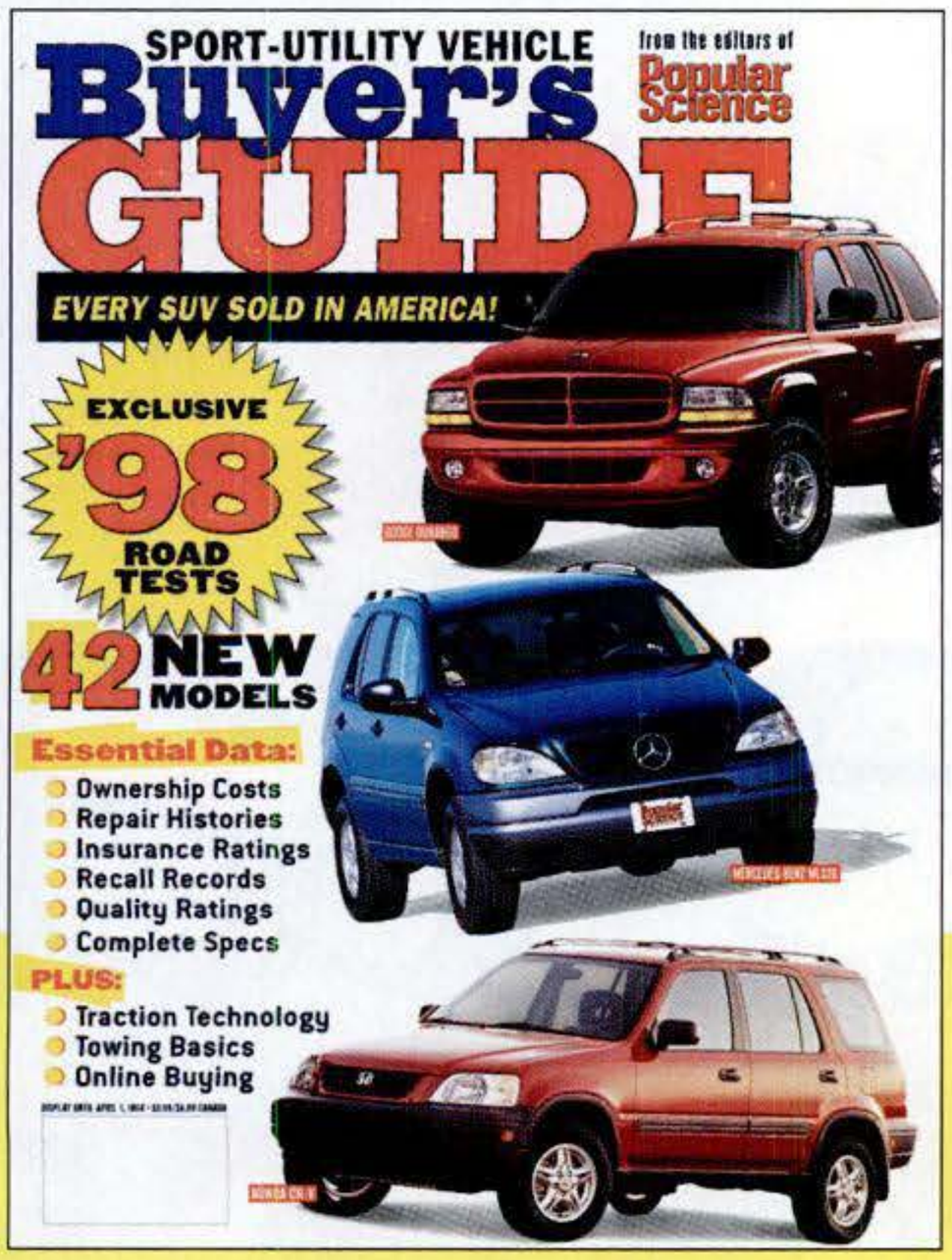
The acronym means magnetic digital versatile disc, and it applies to a new 3.5-inch removable storage medium with 2.1 gigabytes of capacity. That's enough to record 133 minutes of video (sufficient for most movies) using MPEG2 digital compression. Such recordings would have the quality of Super VHS videotape—about 420 lines of horizontal resolution, versus about 480 for digital satellite TV and 500 for DVD.

M-DVD is the brainchild of Pleasantwood, California-based Castlewood Systems and already has the backing of Sanyo Electronics, which has made a prototype VCR-like deck. Castlewood, founded by Seagate and Syquest veteran Syed Iftikar, says M-DVD can be used for storage in a wide range of consumer electronics, computer, and telecommunications products, including TV set-top boxes. The company estimates that an M-DVD drive could sell for $200, and its removable hard-disk cartridge for about $30.

Dubbed Orb as a prototype, M-DVD stores 133 minutes of video on a 3.5-inch disc.

The system achieves its huge capacity by using magneto-resistive technology similar to that which enabled IBM recently to announce a 16.8GB hard drive for desktop PCs. Capacity aside, what makes M-DVD capable of recording high-quality video is its fast data-transfer rate —12.2MB per second, according to Castlewood. By way of comparison, today's 3.5-inch floppy streams data at less than 100 kilobits per second, too slow for motion video. M-DVD can record video at greater resolution for shorter periods of time, says Castlewood: about 72 minutes with DVD-like specs; 48 minutes with studio-master quality; or alternatively, more than 3 hours of CD-quality stereo, or about 2,400 digital snapshots.—*Stephen A. Booth*

SPORT UTILITY VEHICLE BUYER'S GUIDE



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HANDS ON

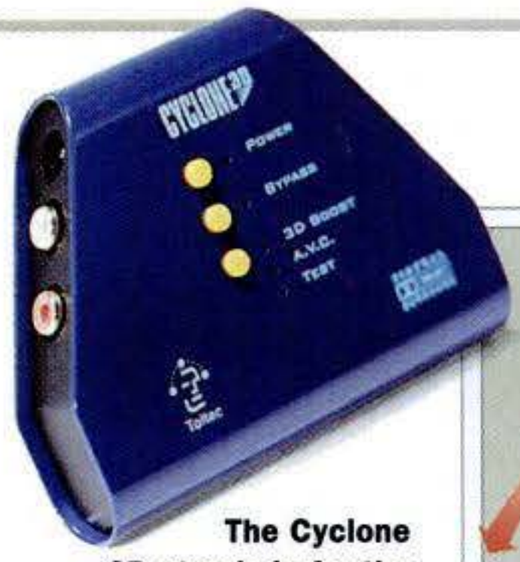
Virtual Surround

A RECENT STUDY by the Electronic Industries Association found that while 90 percent of the respondents would like a home theater, only 5 percent have the necessary equipment. For most people, the complexity of installation and the cost of components are big deterrents.

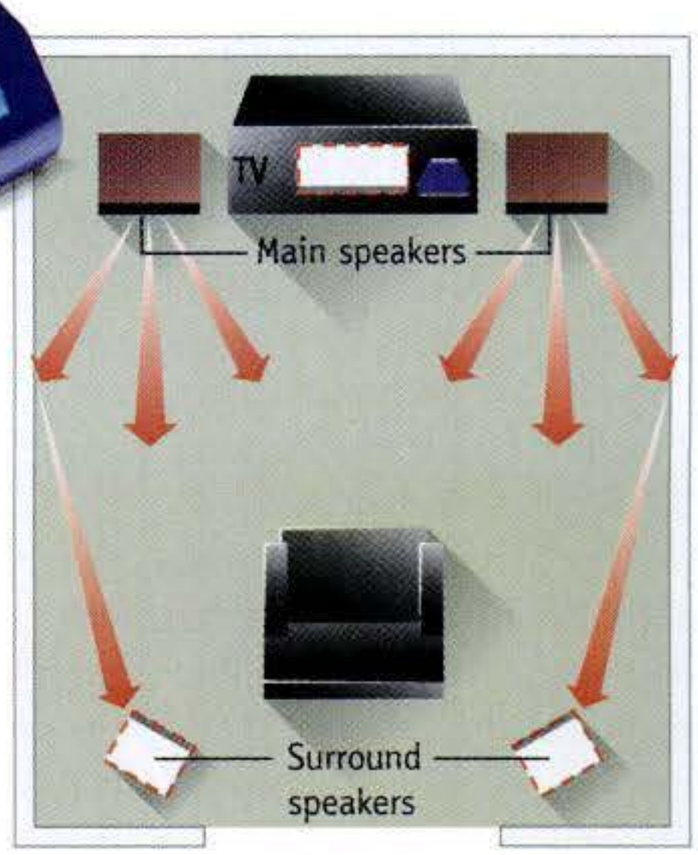
Perhaps the largest investment involves the addition of speakers required for surround sound.

If cost and space are holding you back, you may want to try a new palm-size device from Virtual Listening Systems of Gainesville, Florida, called the Cyclone 3D, which offers a surround sound effect from only two speakers instead of the normal five.

Listing for $99, the Cyclone 3D connects between your VCR and your stereo receiver or between your VCR and stereo TV. The Cyclone 3D uses a variation of Dolby surround processing, called Virtual Dolby Surround, to decode the audio signals that would normally be heard through rear speakers, for example.



The Cyclone 3D stands in for the center and rear channel speakers of a home theater.



GREG MAXSON

While the effect wasn't as pronounced as with a five-speaker setup, the Cyclone 3D device did a credible job of making the sound more encompassing. The experience was similar to the surround sound attained by RCA's SRS system, which is now being built into many of the company's newer TVs.

The Cyclone 3D also brings extra options. A 3D Boost increases the bass and an automatic control increases the volume of quiet passages such as dialog while decreasing louder sounds—useful if you don't want to disturb the neighbors.—*F.V.*

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HOME THEATER

Wall of Sound

YOU'VE GOT THE big screen, the speakers, and some type of surround sound circuitry, whether it be Dolby Pro Logic, DTS, or THX. You crank up the volume, but the audio doesn't quite sound right—the dialog is continuously overwhelmed by the movie's sonic effects, for example.

Most of the time, such problems can be solved by some adjustment of the control settings or by varying the speaker placement. But if remedies like these fail, the walls themselves may be the problem. Depending on the construction material used, some walls either absorb or reflect too much sound, souring the home-theater system sound.

Owens-Corning, the well-known insulation maker, is branching out with the development of an acoustic panel designed to improve the sound in rooms. These panels can be used in new construction or to retrofit a room, much the same way as a homeowner would panel a basement, for example. The panels can be mechanically fastened over existing drywall in any size room. The panels can also be covered with fabric, if so desired.

The panels, collectively known as the Acoustic Room System, are made from Fiberglas and gypsum boards laminated together. Each side is covered with a glass-fiber mat treated in such a way that one side reflects sound while the other absorbs it. By placing the boards around a room and experimenting with which side of the board to expose, an ideal acoustic environment can be created, says Owens-Corning.—*F.V.*

GPS

Tiny Chip Sparks Growth

GET READY FOR a slew of products offering Global Positioning System navigation. SiRF Technology of Sunnyvale, California, a maker of GPS hardware, has developed a GPS chip that is inexpensive and requires low power, so it can bring new capability to a wide variety of small, battery-powered devices such as cellular phones and PDAs, where power consumption is an issue. The amount of power used by the chip is significantly less than that of the previous generation chip. The new chip may also make a variety of such new devices as child-locator systems both practical and affordable. In addition, the new GPS chip should be a more affordable feature for cars.—*F.V.*

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AUTOMOTIVE

EDITED BY DAN McCOSH

ENGINES

Running Clean

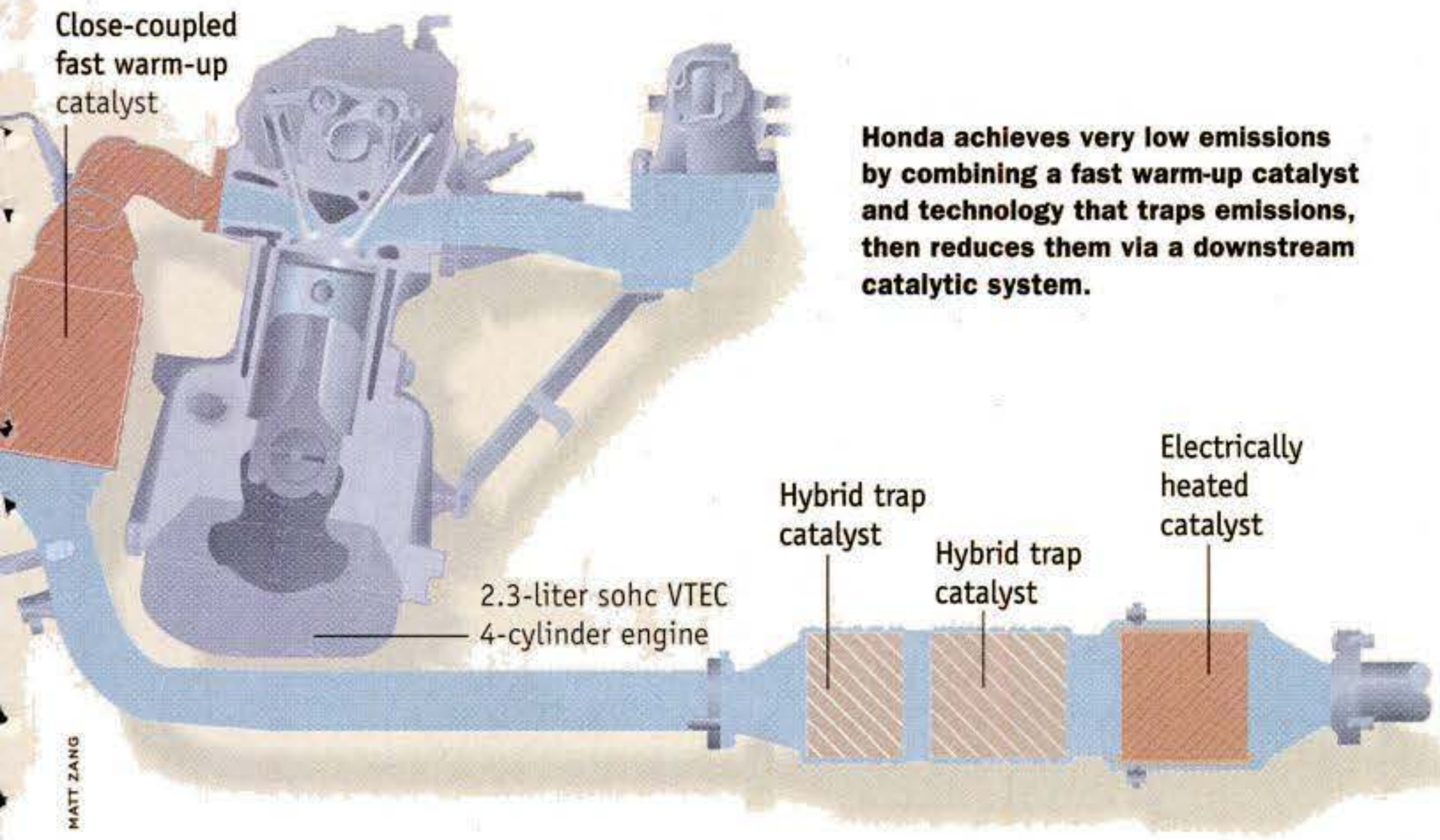
HONDA HAS introduced an experimental car that it claims is as environmentally friendly as an electric vehicle—that is, if the EV includes its fair share of generating-plant emissions. The 2.3-liter four-cylinder Accord model, called a Z-LEV (zero-level emissions vehicle) by its maker, uses variable valve timing and lift in conjunction with three-phase emission controls.

Emissions from unburned hydrocarbons are normally highest the first few seconds after a cold start, when conventional catalysts are ineffective. Honda's Z-LEV strategy calls for an ultra-lean air-fuel mixture during this first phase. Unburned hydrocarbons are temporarily stored in a special hybrid catalyst for processing later. Loaded with zeolite hydrous-aluminum silicate material, this device acts as both a trap and a high-efficiency oxidation catalyst.

During phase two, a close-coupled catalyst is activated by exhaust heat while the underfloor catalyst most distant from the engine is electrically heated. Hydrocarbons stored in the trap catalyst are released for oxidation into water vapor and carbon dioxide.

Phase three is normal operation after warm-up; the combination of a 32-bit engine-control computer, Honda's variable valve timing and lift system, and the high-efficiency catalysts effectively cleanse the exhaust stream of emissions.

Honda's Z-LEV reduces unburned hydrocarbons to one-tenth of 1 percent of that of an uncontrolled car or one-tenth of California's stringent Ultra Low Emissions Vehicle standard. On a smoggy Southern California day, air ingested by the engine is six times dirtier than what leaves the exhaust pipe. Two problems remain: the experimental system's cost (about $1,000 beyond conventional emission controls) and its susceptibility to contamination by sulfur in the gasoline supply. Japan's fuel is virtually sulfur-free, and California's fuel is low in sulfur, but there are wide variations in the rest of the U.S.—*Don Sherman*



MATT ZANG

Honda achieves very low emissions by combining a fast warm-up catalyst and technology that traps emissions, then reduces them via a downstream catalytic system.

PREVIEW DRIVE

Ready for Super Duty

THE 1999 FORD Super Duty series pickups rank with the behemoths of the light-truck world. Built on a chassis that's different from the under-8,500-pound GVW F-Series', the trucks now have a cab design that distinguishes them as well.

A new body cloaks a revised chassis for Ford's new Super Duty pickups.

The styling features a massive chrome grille and bulging fender flares, cues that this is a big truck designed for heavy use. Ford estimates about a third of the Super Duty series are being employed for chores such as trailer and RV towing; the remainder are in commercial service.

Forty-four choices of vehicle configuration are available, compared with 24 on the 1998 series. The broad range of body styles now includes a four-door supercab, a nod to the growing personal use of these trucks.

The Super Duty chassis retains the twin I-beam front axle that has been replaced on Ford's smaller trucks by an upper and lower A-arm. The twin I-beam suspension is rugged but tends to allow unwanted changes in wheel alignment. Ford's solution was to rework and retune this design, along with adding new steering gear. The combination gives the truck a new precision on the highway.

New engines power these behemoths: a 5.4-liter V8, a 6.8-liter V10, and an improved version of the turbocharged, intercooled 7.3-liter diesel. Prices range from $19,200 to $34,200.—*D.M.*

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Want better fuel economy? Just replace your oxygen sensor with a new one from Bosch next time you do a tune-up. It'll help your engine get the optimal air/fuel mixture. That improves your car's performance, reduces air pollution, and saves you money in fuel costs.

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TECHNOLOGY

Batteryless Starting?

ULTRACAPACITORS—capacitors that have sufficient energy storage to replace batteries for electric or hybrid cars—are still in the research stage. But a one-off demonstration of the potential to store electricity without a battery is already running in an old pickup truck in California.

Replacing the battery in his 1982 Ford pickup with a 150-farad capacitor (about 1,000 times larger than those in common electrical appliances) built for the Russian military has allowed engineer Larry Schlussler to start his truck without a battery. The experimental rig provides energy for several starts. The capacitor is recharged by the alternator.

The system won't power engine accessories, and self-discharges rapidly—although it can be topped off via a solar cell. Advantages include longevity and avoidance of toxic lead.—*D.M.*

PREVIEW DRIVE

Reviving the Wagon

WITH DUE RESPECT to Mark Twain, reports of the death of the station wagon are highly exaggerated. Mercedes-Benz is doing what it can to sponsor a resurgence of this traditional family favorite by reintroducing a more spacious midsize car to the lineup after a two-year hiatus. The new E320 wagon has the usual long roof and hinged-hatch access to its cargo hold, but practically no increase in length over the comparable sedan.

The standard seating array is buckets up front, a 60/40-split folding second row, and a rear-facing aft bench suitable for two children. The middle seat is easily removed. Reconfigured for ambitious weekend projects, the E320 wagon will swallow 82.6 cubic feet of gardening supplies and building materials, which beats the Audi A6, Jeep Grand Cherokee, and Volvo V70.

Aimed at customers who need extra versatility but can't stand the prospect of owning a minivan or SUV, the E320 drives little different from its sedan counterpart. The 3.2-liter 18-valve dohc V6 under the hood (a new engine shared with the ML320) delivers 221 energetic horsepower with a torque curve that's dead flat between 3,000 and 4,800 rpm.

A modest weight increase of 210 pounds and chassis balance that's better than in the four-door result in confident road manners. Optional gear includes the ML's full-time four-wheel drive (minus low range) and the ESP stability-enhancement system Mercedes-Benz introduced two years ago. Pricing starts at $46,500 for rear drive and $49,250 for all-wheel drive.—*D.S.*

After a two-year manufacturing hiatus, Mercedes is introducing a more spacious wagon.

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RACING

Salt Flats Revived

THE BONNEVILLE Salt Flats, near Wendover, Utah, site of numerous attempts at land-speed records, have been getting smaller for some 75 years as a local salt-mining operation pumps brine from the surface of the lake bed.

A five-year plan to reverse the erosion now is under way. The lake will be flooded in winter with brine from the salt-mine's holding ponds. The mine has no further need for the brine after potash has been extracted. The plan is to add about a half inch of salt a year to restore the dwindling lake bed.

The shrinking lake has severely limited top speeds at Bonneville as the track shrinks, causing racers to seek other sites.—*D.M.*

PREVIEW DRIVE

Touching All the Bases

TOYOTA'S 1998 Land Cruiser scores the automotive equivalent of baseball's grand slam: It's faster, bigger, tougher, and more comfortable to ride in than its predecessor.

Extra acceleration and power come courtesy of a 4.7-liter 36-valve dohc V8, a first for a vehicle wearing the Toyota badge. It's based on the engine used in the Lexus LS/GS 400 series. And that spells speed: Zero to 60 in 9.9 seconds, about 2 seconds better than last year's six-cylinder.

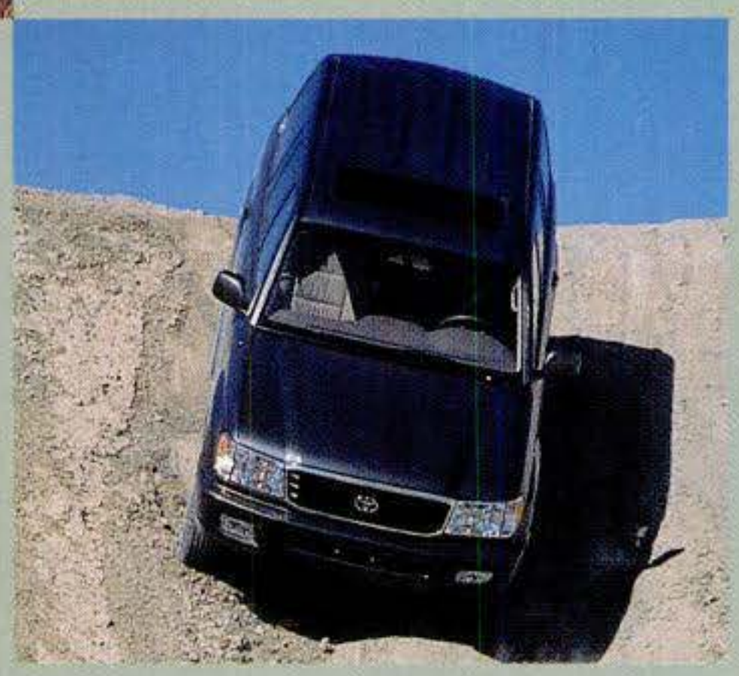
The new Toyota Land Cruiser adds a high-tech V8 engine adapted from the Lexus sedans to power the SUV.

The extra quickness is especially commendable, because at 5,225 pounds, the '98 Cruiser outweighs its predecessor by about 400 pounds. Some of that heft comes from chassis reinforcement—50 percent more cross members, for example—for more structural rigidity and less flex.

The added frame strength was evident when we drove both the '97 and then the '98 models across the broken washboard roads and steep dirt mounds of the Anza Borrego desert at the foot of California's Santa Rosa Mountains. The '98 Cruiser floated more smoothly over ruts and gullies. In low-range four-wheel drive with the optional fully locking differential set, we clambered over roller-coaster-like inclines.

A new independent front suspension factored big in our ride comfort. Reconfigured cab-mount cushions and silencer material throughout the cabin lent an air of serenity, even when stray rocks were banging the body hard.

Topping off the Cruiser's four-base hit, the new front seat slides back an additional 2 inches, with 3 inches of added legroom stretch in the rear. And for a final flourish, Toyota lines a last clean single up the middle—there are now as many as nine cupholders; last year's model had only two.



The upgraded Toyota Land Cruiser is slated to be available in March. At press time, no pricing details had been announced.—*Bob Sillery*

EMISSIONS

Ignoring the Red Light?

THE NEWEST RED warning light on your instrument panel isn't telling you that your engine is in danger of failing. The onboard diagnostic systems (OBD II) mandated for 1997 light vehicles use a red light to warn that the emission control system is not operating properly, hence adding to air pollution.

But do drivers, some who casually ignore a low-oil-pressure telltale, bring their car in for adjustment or repair? The answer has implications for future emission legislation aimed at keeping catalysts working for the life of the car, say researchers at Colorado State University, who have kicked off a study of how drivers are reacting to an emission-warning light.

Among the potential solutions being considered are transponders that radio a failure to a central emission control monitoring group, even pinpointing the location of the offending vehicle. Critics say that distant diagnosis raises privacy issues, however.—*D.M.*

SAFETY

Beating Drowsiness

A STUDY TO SEE whether a steering-wheel sensor can detect the onset of drowsiness is being undertaken by Carnegie Mellon Research Institute, of Pittsburgh.

The study—aimed primarily at long-haul truck drivers—will use a series of cameras to detect eye movements that indicate the driver is falling asleep. The movements will be correlated to steering wheel movements, revealing whether the driver is or isn't making normal corrections. The sensor data ultimately will be incorporated into a system that shakes the driver awake, or sounds an alarm, say researchers.—*D.M.*

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PREVIEW DRIVE

A New SUV Prescription

ALTHOUGH LEXUS IS adamant that its new RX 300 is not designed for "serious" off-road driving, our test route quickly led us down rutted, slush-covered mountain trails, where the RX 300 performed well.

The RX 300 lacks the high ground clearance and locking differentials of real back-country bashers, but when it's equipped with full-time four-wheel drive it can easily handle most off-pavement driving, and it delivers an extra measure of security on slurpy winter roads.

The standard RX 300 comes with front-wheel drive, and, like Toyota's highly successful RAV4, employs unit-body construction and a number of passenger-car components. Its 3.0-liter dohc 24-valve aluminum V6 is essentially the Camry/Lexus ES 300 engine, with the addition of Toyota's ingenious new continuously variable valve timing system, which boosts output to 220 horsepower and 222 foot-pounds of torque.

The combination of plenty of smooth power and the relatively low curb weight that goes with a unit body (3,789 pounds for the two-wheel-drive version; 4,037 with four-wheel drive) yields brisk acceleration by SUV standards—0-to-60 mph in 8.5 seconds—and also contributes to handling response that compares favorably with the ES 300 sedan. Fuel economy likewise is improved due to the relatively low weight.

Manufacturers of sport-utilities have discovered that most buyers want a commanding view of the road, with passenger-car comfort, quiet, convenience, and performance, plus, for many, the extra traction of four-wheel drive. And that's exactly what the RX 300 delivers. With considerable style.

Lexus officials concede that their new offering is targeted at the Mercedes-Benz ML320, and priced it accordingly. The two-wheel-drive version starts at $31,550, while the four-wheel-drive starts at $32,950.—*Tony Swan*

The new Lexus RX 300 combines the looks of a station wagon with four-wheel-drive capability in a single package.

SAFETY

All-Around Protection

WHY AM I about to swing a sledgehammer against a BMW 740's front side-window glass? Because it's there, and because BMW asked me to prove a point: Despite my mightiest swing, the hammer bounces off the glazing. The window shatters but manages to remain intact.

Two more swings leave the glass still unpenetrated. Plastic between the layers of glass holds the window in place; an inner layer keeps the broken pieces away from occupants.

This $2,600 option on the 740 Series BMWs offers added protection against smash-and-grab thefts and carjacking attempts. It is not bulletproof, though. The lack of bulletproofing is a step down from the glass in the 540 Protection ["Bulletproof Bimmer," Feb.], which also includes other "safety" touches such as bulletproof aramid fabric in the doors. Offering the most protection of all is the 750, details of which BMW, ahem, doesn't discuss.

Safety of another sort is provided by DSC III, BMW's yaw-control system, standard in the '98 540i and the 7 Series. The system features a faster electronic-control unit, plus lateral acceleration, yaw, and brake-pressure sensors to improve vehicle stability, making a spin virtually impossible. The BMW system is similar to that of Mercedes-Benz, with a few differences: It intercedes earlier but not as severely in controlling vehicle dynamics. Though the 740's system is newer than 750iL's, it introduces a shortcoming: Mounted on the master cylinder, it's more audible when it is actuated.

Should traction be lost completely, even DSC III won't bail you out. But BMW's head-protection system ["Best of What's New," Dec. '97], standard on all '98 740 and 750 models, may save you.

Also new for '98 is an "airbag" for the starter cable. On impact, a pyrotechnic in the battery clamp forces a separation in the starter cable, reducing the chance that the high-amperage cable could spark a fire. Meanwhile, a smaller fuse-protected cable provides power to unlock doors and run the hazard flashers.—*John Matras*

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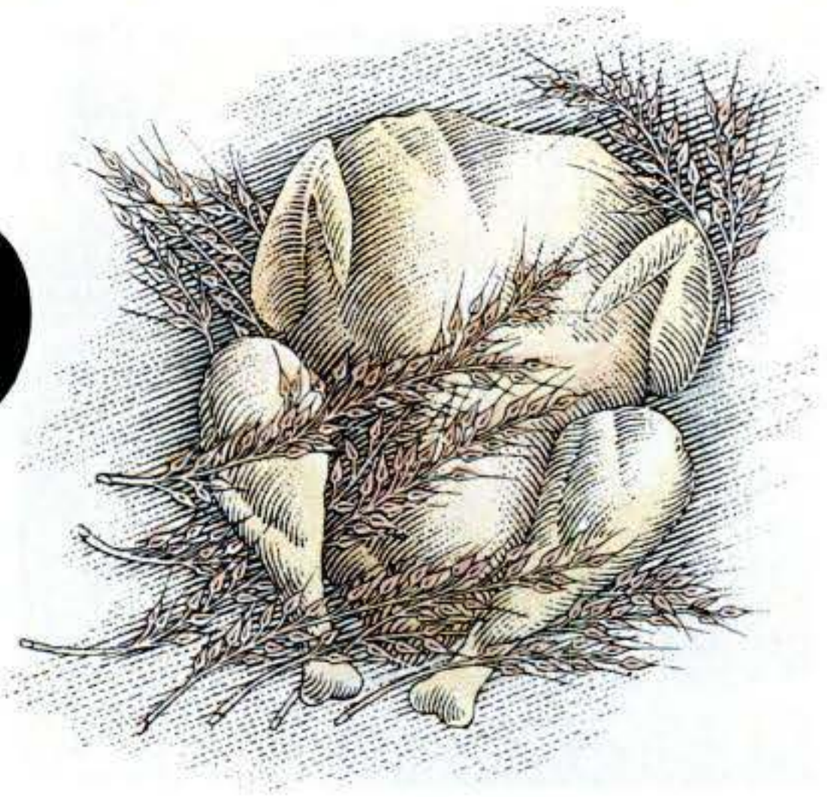
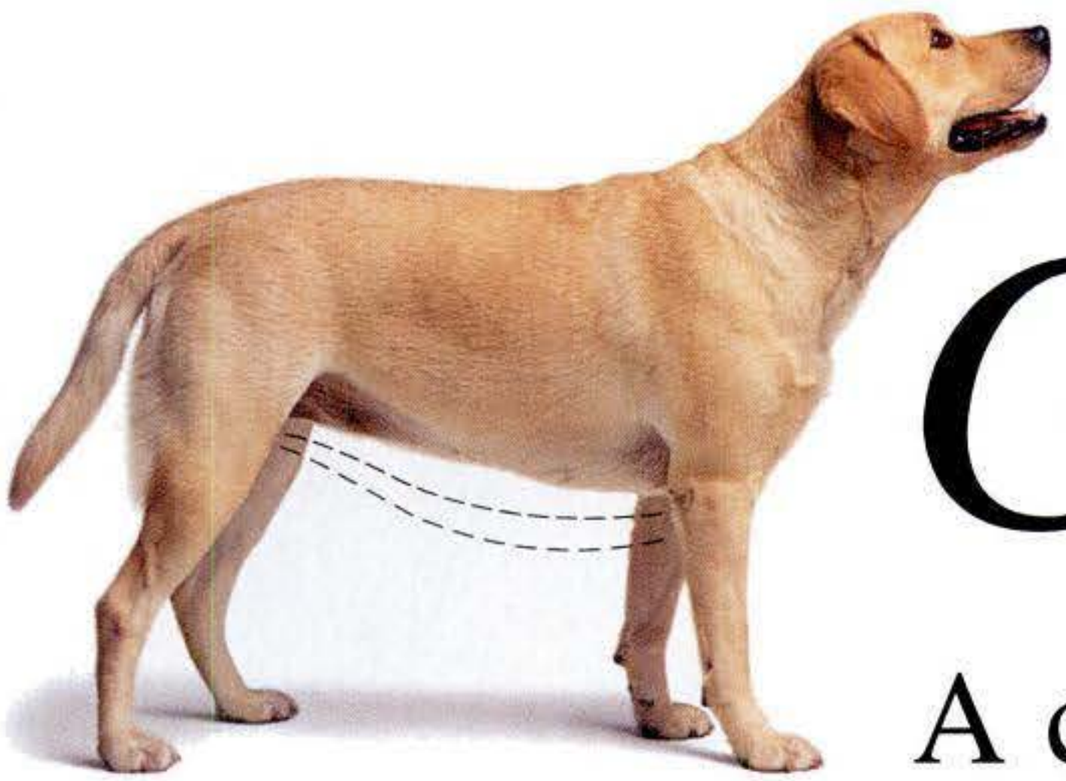
He Doesn't Have To

Give Up



The Finer Tastes

He's Grown

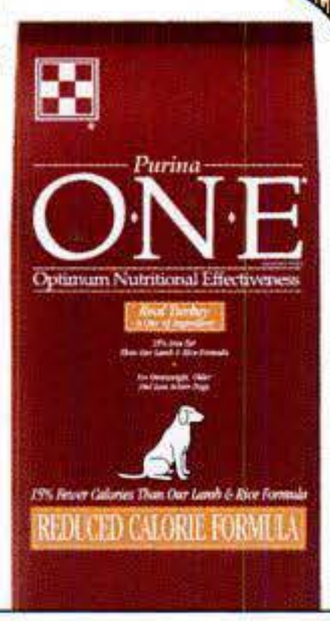


(And We Do Mean

Grown)

Accustomed To.

Even though you wouldn't necessarily call him a picky eater, he won't go near a diet dog food. Well, can you blame him? Other reduced-calorie dry dog foods are often made with corn or grain as their first ingredient. Not the case with Purina O·N·E® brand Reduced Calorie Formula. It's the only diet dog food you can find anywhere that's made with real turkey as its number one ingredient. Which means not only is it a nutritious way to provide your adult dog with all of the protein and energy he needs but, more importantly, your little gourmand probably won't even know he's on a diet. For more information or to receive your free sample, call 1-800-787-0078, extension 43.



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The longest life.

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and forth. And back and forth.

When designing the Bosch Micro Edge Excel, we weren't satisfied until we got it right. The result is a revolutionary wiper blade that not only cleans better but also lasts longer.

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* Always wear your safety belt and secure children in the rear seat.

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HOME TECHNOLOGY

EDITED BY WILLIAM G. PHILLIPS

BUILDING

The Healthy Home

WHEN BRIDGET Harrington and Bart Main hired a contractor to renovate their 75-year-old Minnesota home a few years ago, they got more than they bargained for. "When the contractors pulled apart the walls, the air filled with insulation and plaster dust," Main says. Sloppy installation of attic insulation allowed moisture to condense and mold to form. Two water heaters installed without a combustion-air supply leaked carbon monoxide into the home. The entire family got sick. The couple's daughter developed a mold allergy that permanently weakened her immune system.

So when the family needed a bigger home last year, it's no wonder they decided to build a new house. What's more, they decided to become the first participants in the American Lung Association (ALA) Healthy Home Program. The program, in which ALA certifies new homes for good indoor-air quality, has trained 60 builders and is hooking them up with interested buyers.

Qualifying homes must meet stringent standards, including an insulated, airtight envelope—for less infiltration of outside air—and balanced mechanical ventilation, techniques that, says ALA's Liz Wortman, also increase energy efficiency.

But ALA goes beyond efficiency by limiting the sources of indoor pollution. Paints, solvents, and adhesives must contain little or no volatile organic compounds. Fuel-burning appliances must have sealed combustion. A central vacuum must exhaust to the outdoors. And all air supplied to the house must be filtered. ALA inspectors monitor construction, then test the completed house.

With Americans spending more time indoors, the program isn't just for the chemically sensitive, says Wortman.—*Charles Wardell*

SHELTERSOURCE INC./LEE THOMAS KJOS

The Health House seals out moisture and pollutants with a tight, well-insulated building shell (left) and foundation (above).

RADON

Fight with Power

THE FUTURE OF radon removal may be as simple as powering up your living room. In tests conducted under a grant from the EPA, SR Environmental of Amherst, New York, has shown that electrically charging a few furniture surfaces continuously can eliminate as much as 90 percent of radon particles circulating in a large room.

Taking advantage of radon particles' affinity for highly charged surfaces, scientists attached a 10-kilovolt power supply to various pieces of furniture—bookcases, sofas, tables. After about 3 hours, they found the airborne concentration of radon had decreased 76 to 90 percent, depending on how large a surface area was charged.

The charged surfaces also attracted other pollutants, such as pollen, spores, cigarette smoke, and dust. That's good for clearing the air, but bad for occupants who use the furniture. The company is now attempting to figure out how to either repeatedly clean these surfaces or create a single collection plate—say, a bookcase—with a surface area large enough to be effective.

Radon, a naturally occurring radioactive gas, is the second-leading cause of lung cancer in the United States. The gas emanates from trace amounts of radium found in soil underneath or adjacent to many homes. The gas itself doesn't do the damage; rather, small particles emitted from its decay seep through cracks or porous building materials and are inhaled.

SR Environmental is now conducting more studies to determine whether the system is feasible. One benefit: It would cost about $400, half that of the traditional method of subslab piping to remove radon.—*Gunjan Sinha*

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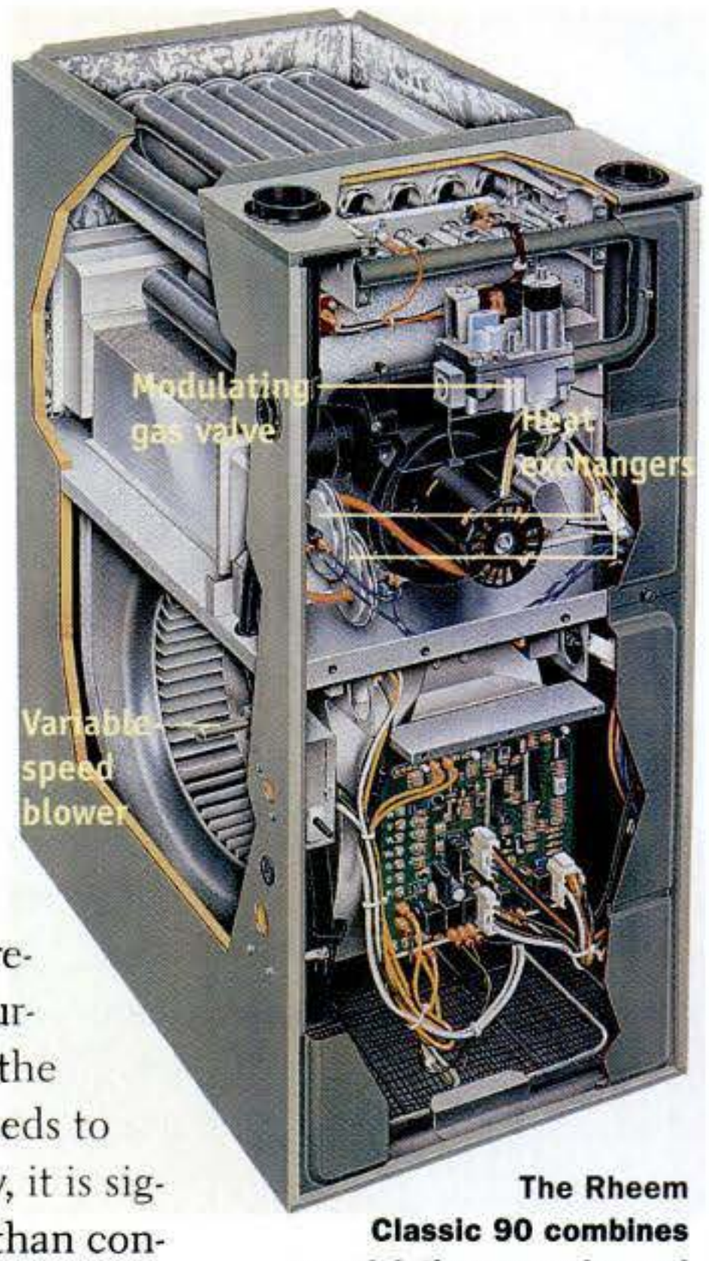
HEATING

A Furnace with Finesse

EVER NOTICE HOW your house is chilly one moment and too warm the next? That's because setting your home's thermostat at a certain level doesn't guarantee the temperature will remain there. Most forced-air heating systems kick on when the house falls a few degrees below the thermostat setting, and continue blasting heat until the house is several degrees above it.

A new furnace from Rheem, the Classic 90 Plus with Contour Comfort Control, promises to minimize these fluctuations. The system is the first to combine a modulating gas valve with a variable-speed blower, enabling the Classic 90 Plus to operate at anywhere from 40 to 100 percent capacity. The gas valve, the first furnace unit that can operate at more than just a few speeds, continuously regulates the amount of fuel necessary to heat the home, while the blower ensures efficient operation.

The system does more work than a typical furnace—that is, it operates a larger portion of the day. But Rheem claims that the Classic 90 Plus has an annual fuel utilization efficiency of 94—which is a respectable rating. Furthermore, because the furnace seldom needs to run at full capacity, it is significantly quieter than conventional furnaces, which produce a loud rumbling noise every time they abruptly force a large volume of air into the ductwork. In fact, the variable-speed blower ramps up slowly to ensure quiet operation.



The Rheem Classic 90 combines a modulating gas valve and a variable-speed blower to ensure consistent heating.

The furnace works with its own programmable thermostat, so homeowners can set it to automatically drop to 64°F at night or during the workday, for example, or rise to a toasty 70°F on Saturday mornings. In addition, homeowners can add optional remote sensors to particularly cold or warm rooms to help even out the house's overall temperature.

Although the company has not yet announced the price of the system—which will be available to consumers beginning this spring—Rheem predicts that the Classic 90 Plus will cost about $1,000 more than a conventional furnace.—*Judith Anne Gunther*

GENERATORS

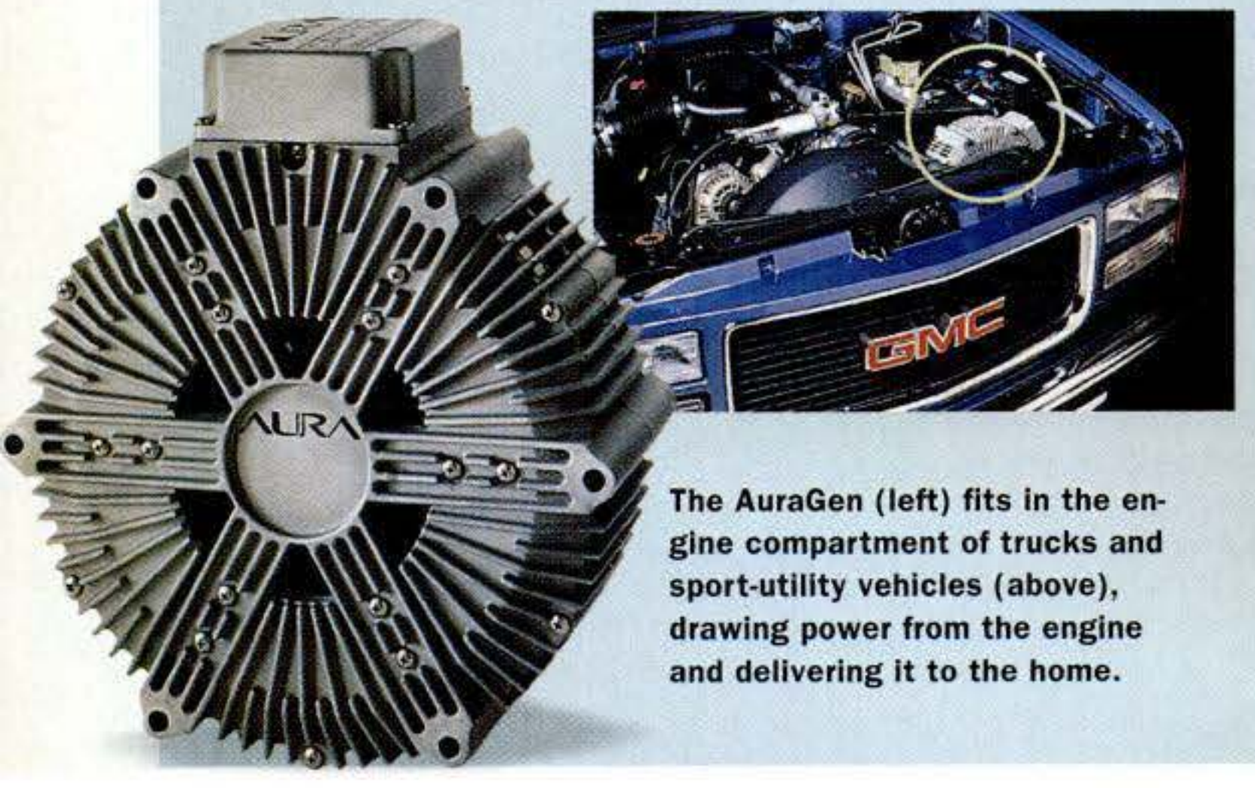
Driving Power Home

TIRED OF COMBATING power outages with candles? Or having to prime that long-neglected gas generator just to make dinner? A new generator from Aura Systems promises to deliver enough electricity during an outage to power a home's major appliances—from the car in your driveway.

The AuraGen G5000 mobile generator mounts inside a vehicle's engine compartment and acts as a secondary crank pulley, drawing energy from the idling engine. Power is delivered to the home through a heavy-duty extension cord plugged into a transfer switch connected to the home's fuse box. The system delivers 5,000 watts, enough to power lights, a refrigerator, microwave, television, computer, and coffee pot at the same time. A 30-gallon tank of gas can provide up to two days of power. The system does not affect the vehicle's power or gas mileage, or the manufacturer's warranty.

The system, expected to cost around $2,500, will be available this month for trucks and sport-utility vehicles. A version for passenger cars will hit the market by mid-1999. The 70-pound system includes the generator, mounting brackets, a belt-pulley set, the transfer switch, and two outdoor power outlets that can be mounted onto a vehicle, allowing devices to be plugged in directly—a nice feature for campers.

According to Arthur Schwartz, executive vice president of the El Segundo, California-based company, there are other automobile-based portable generators on the market—notably from Road Power of Fort Worth, Texas—but none are as powerful or designed specifically for use during a power outage.—*Joseph Baneth Allen*



The AuraGen (left) fits in the engine compartment of trucks and sport-utility vehicles (above), drawing power from the engine and delivering it to the home.

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HEAR WHY THE BOSE® WAVE® RADIO WAS NAMED A "BEST NEW PRODUCT OF 1994" BY *BUSINESS WEEK*.

Tabletop radios are popular for their convenience and small size. But their sound quality leaves much to be desired. No one really expects high-fidelity sound from a radio. Until now.

Bose presents the Wave radio. It's the one radio acclaimed by leading audio critics. Because it's the one radio that delivers big, rich, lifelike stereo sound *plus* a small, convenient size.

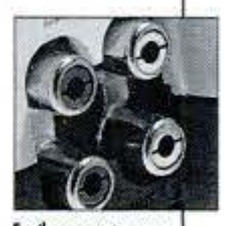
breath of air to fill an entire concert hall, the waveguide produces room-filling sound from a small enclosure. This technology and performance is available in no other radio.

You'll touch a button and hear your favorite music come alive in rich stereo sound. You'll hear every note the way it's *meant* to be heard. The Wave radio measures just 4⅛"H × 14"W × 8¼"D and fits almost anywhere. So you can listen in your bedroom, living room, kitchen, or any room. And with your choice of imperial white or graphite gray, the Wave radio not only fits in any room, it fits any decor.

CALL NOW AND MAKE SIX INTEREST-FREE PAYMENTS.

The Wave radio is available for $349 directly from Bose, the most respected name in sound. So call 1-800-845-BOSE, ext. R7354, to learn more about our in-home trial and satisfaction guarantee. When you call, ask about our six-month installment payment plan. Or, if you prefer, return the coupon below.

Set six AM and six FM stations.



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THE BEST-SOUNDING RADIO YOU CAN BUY.

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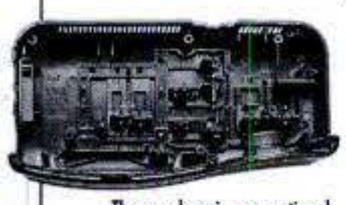
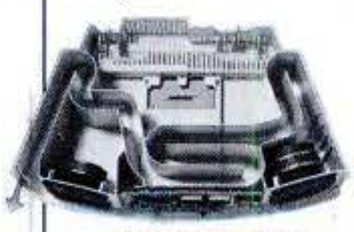


The speakers in conventional radios cannot produce lifelike bass, which is essential for great sound.

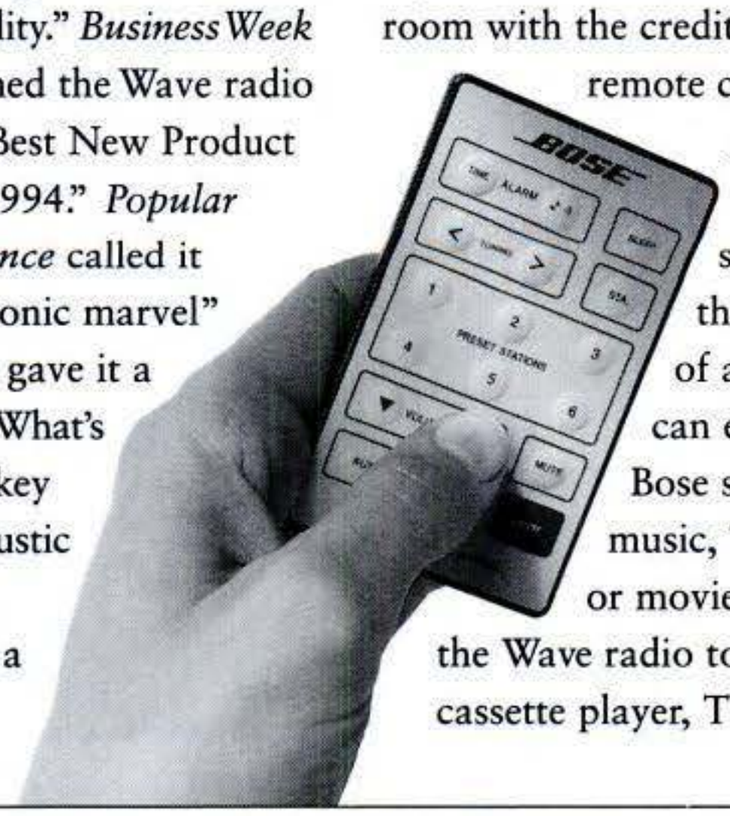


Only the Wave radio with acoustic waveguide speaker technology produces high-quality sound with full, rich bass.

Radio World called the sound "simply amazing…a genuine breakthrough in improved sound quality." *Business Week* named the Wave radio a "Best New Product of 1994." *Popular Science* called it "a sonic marvel" and gave it a prestigious "Best of What's New" award. The key is our patented acoustic waveguide speaker technology. Just as a flute strengthens a

REMOTE-CONTROLLED CONVENIENCE.

Operate the radio from across the room with the credit card-sized remote control. Set six AM and six FM stations, and switch between them at the touch of a button. You can even bring great Bose sound to recorded music, TV programs, or movies by connecting the Wave radio to your CD or cassette player, TV, or VCR.



Wired magazine said it has a "clean, sweet sound that will have your friends wondering where you've hidden your fancy speakers." But you have to hear the Wave radio for yourself to believe it. Call today.

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A Bridge So Far

The longest suspension bridge in the world opens next month in Japan. Never mind that it's in the middle of an earthquake zone.

COURTESY: HONSHU-SHIKOKU BRIDGE AUTHORITY

DRIVE ACROSS THE world's longest suspension bridge and you'll be tempted to check the gas gauge to be sure you have enough fuel to get from one side to the other.

You might also wonder about the wisdom of building Japan's grandest bridge in the middle of an earthquake zone. That may seem like a bad idea, but the bridge's construction has been a decades-old national dream—first proposed in the 1930s—that could only now be fulfilled thanks to today's technological know-how. When it opens on April 5, the Akashi Kaikyo Bridge will be the final link in a chain of spans that connects Japan's four main islands. Travelers will be able to transverse the country via a bridge network that already includes three of the longest suspension bridges in the world.

Everyone knew—or so they thought—that the nearest seismic fault was 90 miles away from the bridge site. So engineers from the Honshu-Shikoku Bridge Authority, formed in 1970, took the necessary precautions, designing the bridge to withstand an earthquake that would measure 8.5 on the Richter scale. Work began in May 1988 on the bridge, which ultimately would measure 12,828 feet, or 2.43 miles, in length. The center span alone is 6,529 feet, or 1.25 miles. The bridge links the main island of Honshu to the small island of Awaji, which, via another smaller bridge, is the gateway to Shikoku, home to 4 million people.

By Dennis Normile & Frank Vizard

By comparison, the longest suspension bridge in the United States (and number six in the world) is New York's 34-year-old Verrazano-Narrows Bridge at 4,260 feet. And the Akashi Kaikyo Bridge positively

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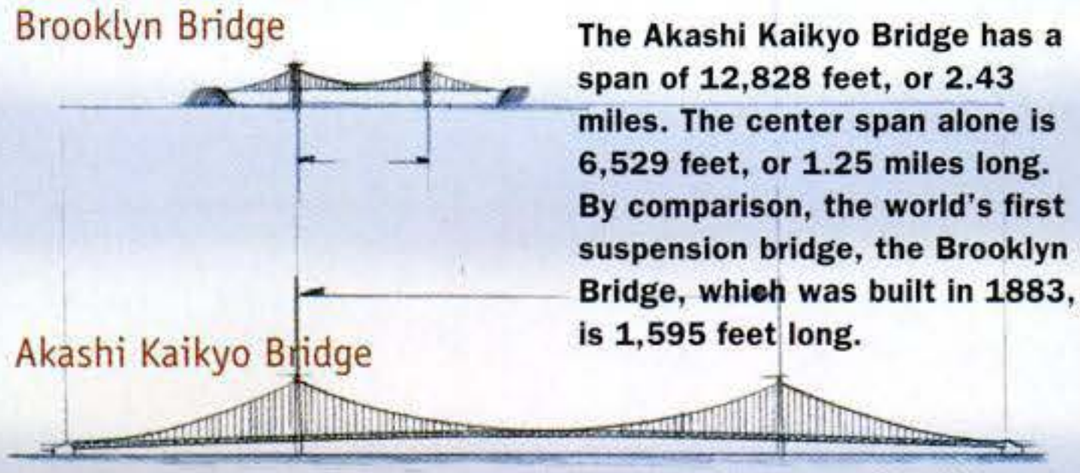
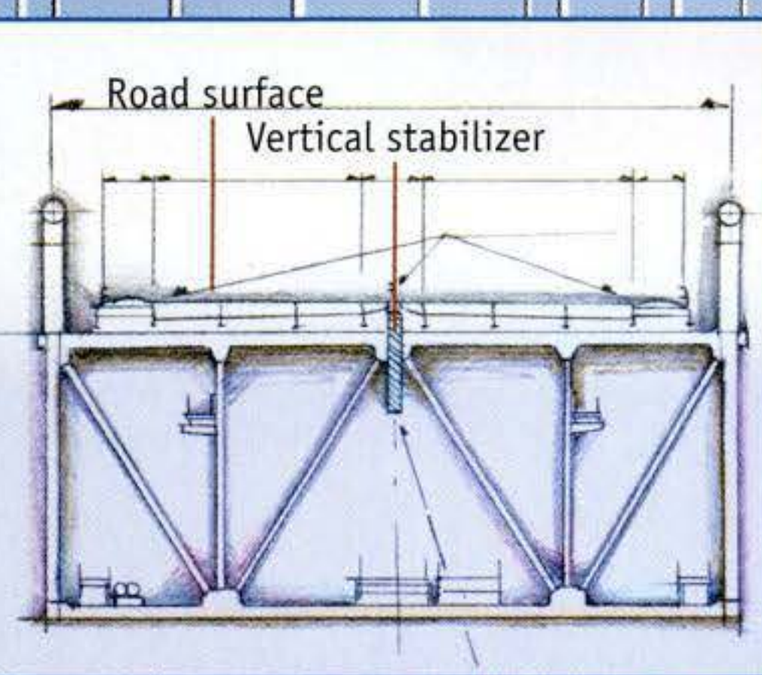
The Longest Bridge

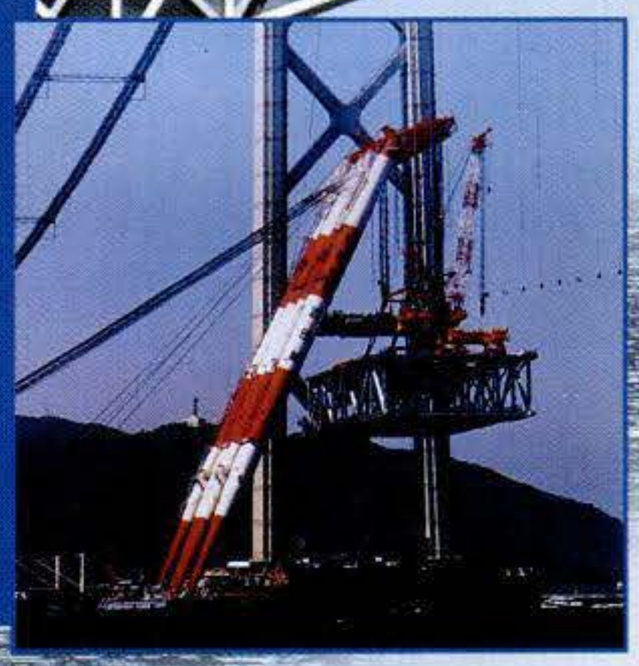
THE AKASHI KAIKYO BRIDGE in Japan is the world's longest suspension bridge, fulfilling a century-old dream of linking the island of Honshu to the island of Shikoku, both major population centers. In addition to the earthquake zone surrounding the bridge, the high winds associated with the region's typhoons were another obstacle to construction. Stresses on the bridge were simulated using a scale model built inside a wind tunnel. Building the bridge meant using new materials and techniques.

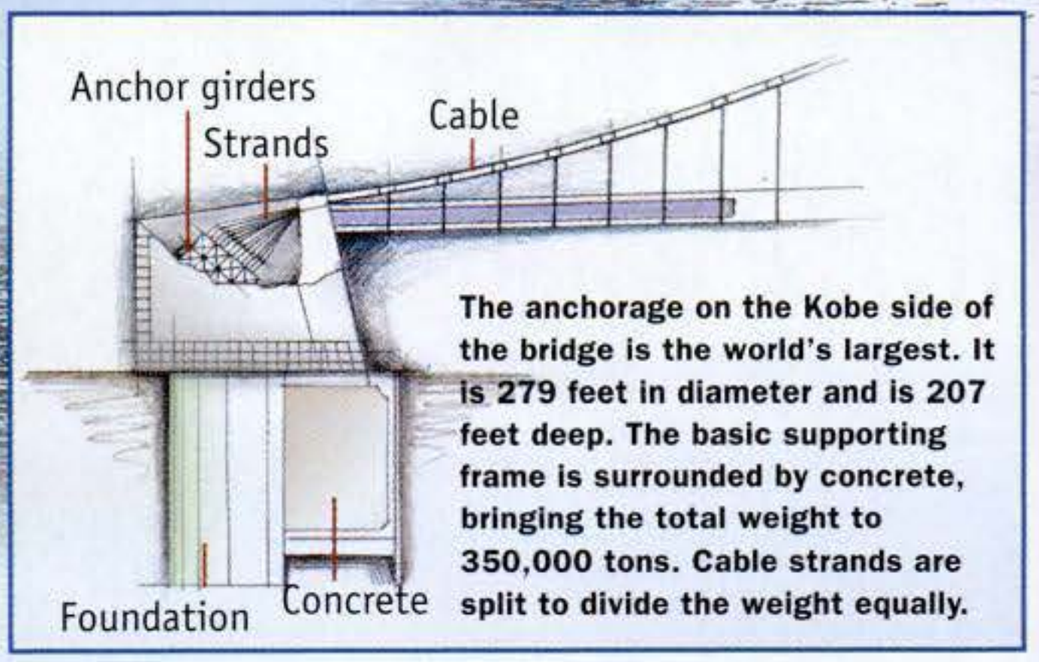


The Akashi Kaikyo Bridge has a span of 12,828 feet, or 2.43 miles. The center span alone is 6,529 feet, or 1.25 miles long. By comparison, the world's first suspension bridge, the Brooklyn Bridge, which was built in 1883, is 1,595 feet long.



A floating crane raised the bridge's girders in sections. Even though the girders are considered strong but lightweight, 90,000 tons of steel were used in their construction. Special vertical stabilizers under the median strip of the deck reduce wind vibration by balancing the pressures on the upper and lower surfaces of the bridge.





The anchorage on the Kobe side of the bridge is the world's largest. It is 279 feet in diameter and is 207 feet deep. The basic supporting frame is surrounded by concrete, bringing the total weight to 350,000 tons. Cable strands are split to divide the weight equally.

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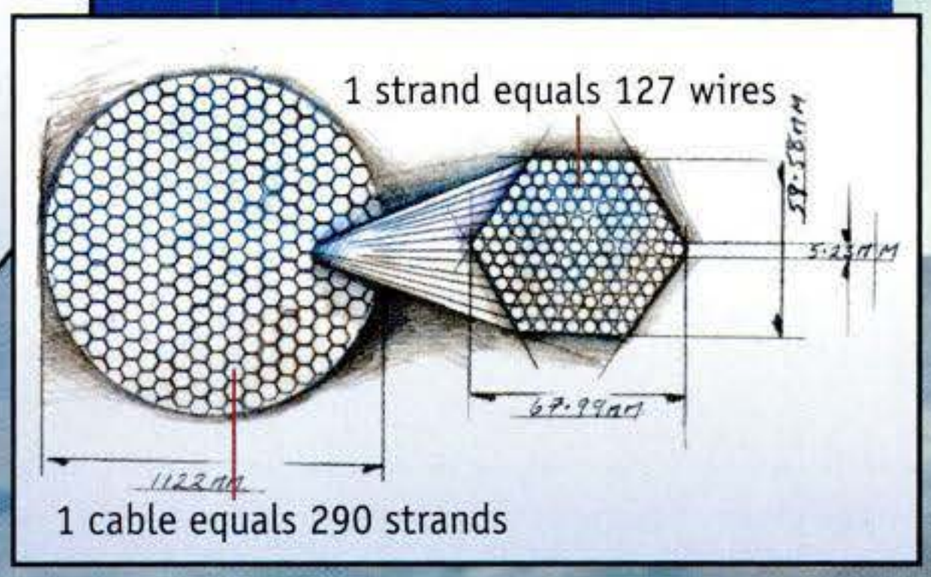
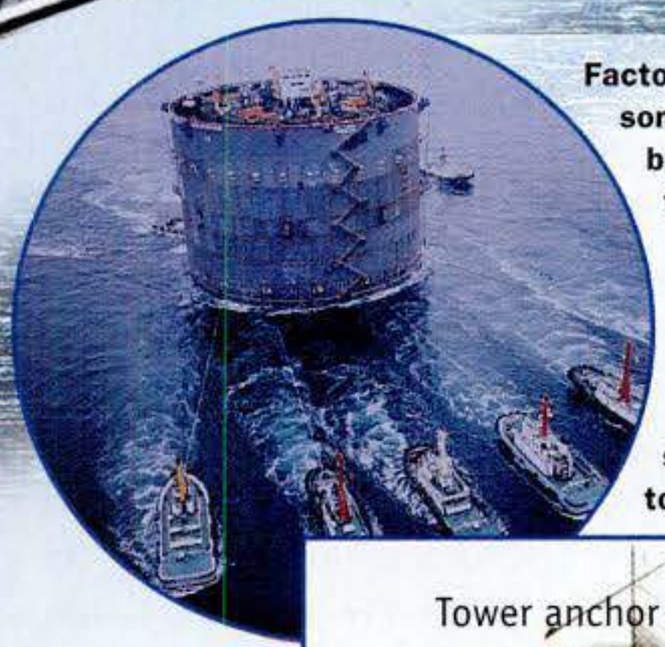
A helicopter flew the pilot rope for the cable to follow.

Two cables—one on each side—hold the bridge roadway but each cable is composed of 290 strands. And each strand, in turn, contains 127 wires made from a new, high-tensile galvanized steel. The total length of the wire is 186,000 miles—enough to circle the globe seven times.

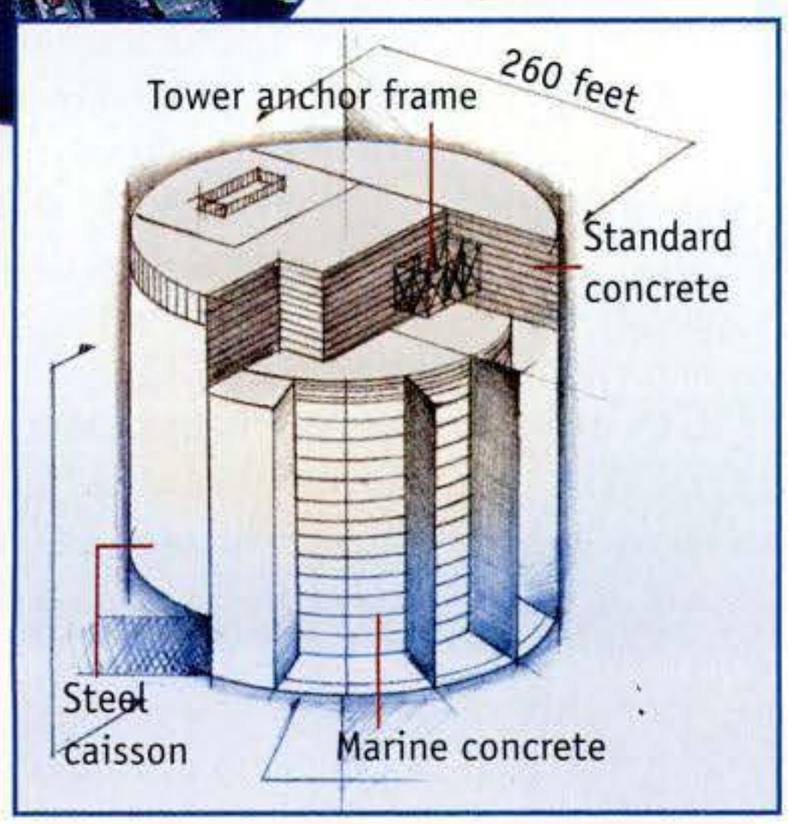


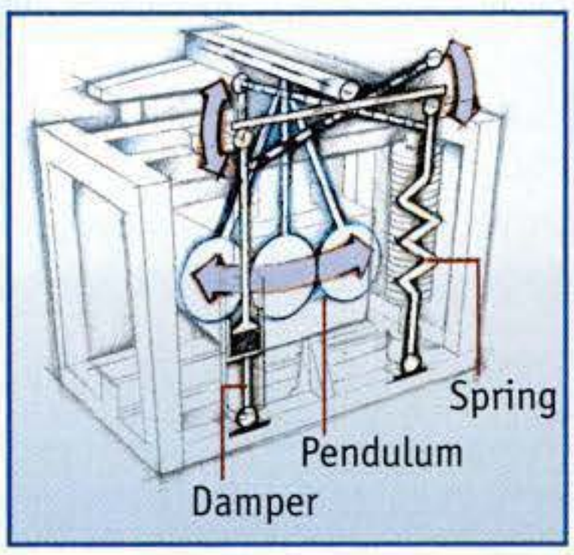
6,529 feet

The bridge towers were built using a boot-strapping crane that constructed the tower one tier at a time. The towers are 30 tiers high, with each tier divided into three sections so as to remain within the lifting capacity of the crane. Mass dampers, weighing 10 tons each, inside the tower work like a pendulum for stability. At 928 feet, each tower is about as tall as France's Eiffel Tower.



Factory-made, hollow caissons were towed to the bridge site to serve as the foundation for the bridge towers. Once in place, the caissons were filled with concrete and sunk into the seabed. They support the 100,000-ton bridge.





COURTESY: HONSHU-SHIKOKU BRIDGE AUTHORITY (3)

INFOGRAPHIC BY DANIELS & DANIELS

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dwarfs the 1,595-foot-long Brooklyn Bridge, which opened in 1883 as the largest suspension bridge of its time.

Despite periodic efforts by New York City dwellers to sell the Brooklyn Bridge to gullible visitors, it is still open to traffic 115 years later. The odds are good that the $3.3 billion Akashi Kaikyo Bridge will last at least as long, because it has already weathered a crisis that would make any Brooklynite shudder.

On January 17, 1995, just after the cables had been set in place, nature delivered a big surprise: an earthquake measuring 7.2 in magnitude. The real shock was that the epicenter was only about 2.5 miles away, along a previously unknown fault line that actually extended under the center span. The earthquake smashed the nearby city of Kobe ["A Wake-up Call from Kobe," Feb. '96], claiming 5,000 lives and destroying 100,000 buildings.

Remarkably, the bridge did little more than stretch a little—it was as if the earthquake drew nothing more than a yawn from the span. The southern pier and anchorage shifted slightly, adding 2.6 feet to the bridge's length. This meant the approaches to the bridge needed to be a little more than 4 feet higher to compensate for the added length. Fortunately, the anchorages are the largest in the world, weighing 350,000 tons and extending to a depth of about 208 feet, so they are hard to shake loose. The towers and cable suffered no damage, and within a month, the redesigned girders accommodated the longer length of the bridge.

In a way, the earthquake was a fitting test for a bridge built under tight restrictions and an eye cast toward impending disaster. In addition to earthquakes, engineers also had to safeguard against the buffeting caused by the 180-mph winds often experienced during typhoon season. The bridge towers alone—each about the size of the Eiffel Tower—are the tallest ever built. A 1-to-100 scale model constructed and tested in a new wind tunnel—the world's largest—helped engineers accurately determine the proper size and shape of the vertical fins called stabilizers that are designed to minimize vibration of the bridge deck. From these tests and studies of seismic activities, engineers devised a number of new approaches to bridge construction.

While engineers designed nearly every aspect of the bridge—right down to the wind-resistant girders—to minimize the effects of any natural disaster, one key element, the mass dampers built into the tower, is unique. Inside the damper is a 10-ton pendulum that swings in the direction opposite to the tower's movement. This effectively dampens the movement of the tower, keeping it stable. All told, 20 mass dampers are in place across the span.

Constructing the six-lane 116-foot-wide Akashi Strait ("kaikyo" means strait) presented a challenge, because shipping still needed to pass through the strait connecting Osaka Bay and Japan's Inland Sea. This is why the center span is so long—the towers had to be built on both sides of the strait's navigable channel. The first step was to prepare the seabed for the massive anchorages and for the piers under the bridge's two towers. Large grab-buckets mounted on floating barges removed 720,000 cubic yards of silt and muck so these concrete foundations could sit on rock. Meanwhile, nearby shipyards were fabricating giant, hollow steel shells, called caissons, that would serve as forms for the concrete piers. The caissons were some 262 feet in diameter and 230 feet high—as tall as a 25-story building. The caissons were floated out of dry dock, towed through the

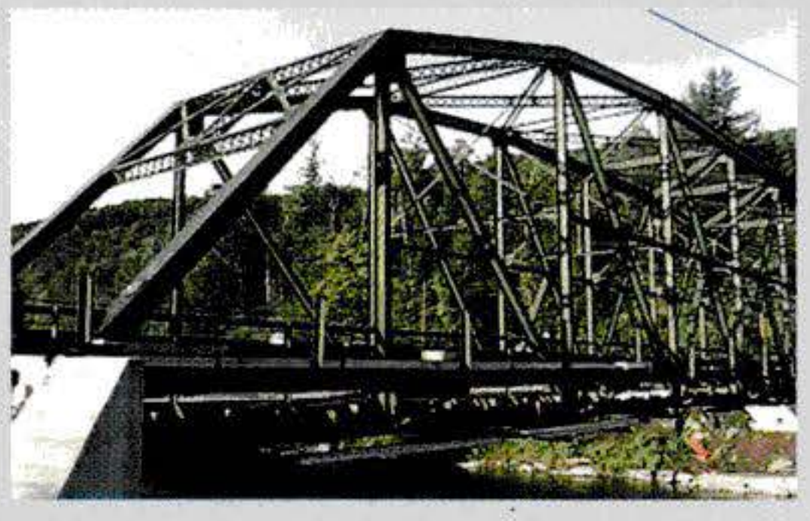
Smart Bridges That Last Longer

WITH AN estimated 230,000 U.S. bridges in need of serious repair, a new emphasis on building bridges that will last a long time with a minimum of maintenance is emerging.

Perhaps the smartest bridge in the United States is the Winooski River Bridge in Waterbury, Vermont. Engineers from the nearby University of Vermont are embedding fiber-optic sensors into the steel truss bridge to check its health. The sensors are linked to a computer that monitors the bridge for cracks, strain, and road-salt corrosion.

On the flip side of the coin is an effort to build bridges using composite materials that require virtually no maintenance—just build 'em and forget 'em. A new 36-ton bridge in Butler County, Ohio, is one of the earliest successes. The Tech 21 bridge is made of lightweight, corrosion-resistant polymers. State officials expect the bridge to last about 150 years, about three times longer than conventional bridges. The new bridge cost about $100,000 to build—roughly twice the norm. The generally higher cost of composite bridges has hindered their widespread adoption.

Low maintenance is also the prime benefit of a new denser and stronger concrete developed by the University of Cincinnati. This high-performance concrete (HPC) allows longer beams to be used, eliminating the need for connecting piers, which collect debris. The denser concrete is more resistant to salt erosion, which corrodes the reinforcing steel bars inside the concrete beam. Ohio plans to build a bridge using HPC near the city of Cambridge this spring.—*F.V.*



Fiber-optic sensors in the Winooski River Bridge in Vermont detect cracks, strain, and corrosion.

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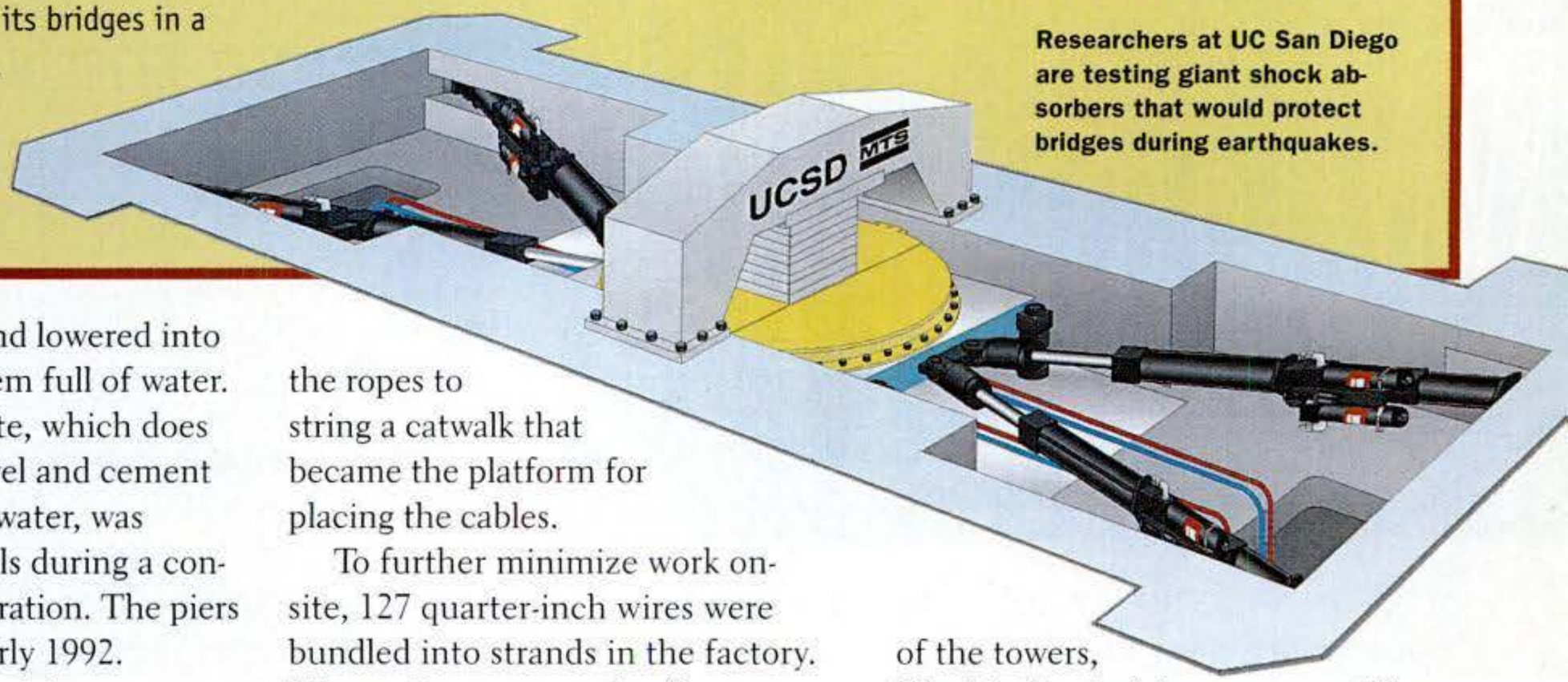
Shock Absorbers for California Bridges

EVER SINCE the 1989 Loma Prieta earthquake in which a 50-foot section of the Bay Bridge between Oakland and San Francisco collapsed, California has been studying ways to make the state's bridges quake-proof. While it now seems likely that the Bay Bridge, which opened in 1936, will be replaced in a project scheduled to begin in 2000, the state is actually retrofitting most of its bridges in a $2.6 billion project.

Among the bigger undertakings is the retrofitting of the 29-year-old San Diego-Coronado Bridge. Strengthening 11 girder hinge sections will limit the bridge's movement during an earthquake. Adding metal stifffeners will also restrict movement. The last major tremor in the area of the bridge was the 1971 San Fernando earthquake.

California is also testing a new technology at the University of California, San Diego. Longer span bridges like the San Diego-Coronado Bridge would be fitted with huge flexible isolation bearings and dampers that crews would place between the superstructure and the supporting columns. These devices would essentially act like shock absorbers to mitigate the effects of a quake.—*F.V.*



Researchers at UC San Diego are testing giant shock absorbers that would protect bridges during earthquakes.

Inland Sea by tugs, and lowered into place by pumping them full of water. Then, marine concrete, which does not separate into gravel and cement when dumped underwater, was pumped into the shells during a continuous three-day operation. The piers were completed in early 1992.

To erect the 928-foot towers, contractors welded the steel plates of the tower legs to form hollow box-like sections called cells, barged them to the site, then stacked and welded them like building blocks. Cell size was limited by the 160-ton capacity of the climbing crane, so each tower was split into 30 tiers roughly 31 feet high. Each tier was made up of three cells, for a total of 180 cells in each tower. The cell sections were constructed in on-shore factories, reducing dangerous on-site work, improving efficiency, and resulting in greater accuracy when the time came to fit the pieces of the bridge together.

The towers were ready for cable to be strung between them in November 1993. The pilot ropes—the first, temporary cables strung from one anchorage over the towers to the other anchorage—are typically pulled across by barge. But since the bridge crosses a shipping lane used by as many as 1,400 vessels each day, a helicopter replaced the barge. After flying the pilot ropes across the straits, workers used the ropes to string a catwalk that became the platform for placing the cables.

To further minimize work on-site, 127 quarter-inch wires were bundled into strands in the factory. These wires were made of a new high-strength steel that is 12.5 percent stronger than in previous bridges. This allowed engineers to use two main cables instead of the four envisioned in preliminary designs, reducing the weight of the bridge and speeding up construction. The strands were wound on spools, hauled to the site, and then pulled from anchorage to anchorage. Each 3.7-foot-diameter cable is made up of 290 strands.

Contractors began erecting the redesigned truss in June 1995, using a 4,000-ton-capacity floating crane to lift into position preassembled sections that were the full width of the bridge, 46 feet deep, and the length of a football field. The contractors would have liked to use this method for the entire truss, but floating cranes would have interfered with navigation. Instead, only the sections adjacent to the towers and anchorages were set this way. For the rest, assembled truss panels averaging 46 feet square were barged to the base of the towers, lifted to the deck by cranes, and then rolled on carts to the working face, where traveling cranes slung them into position.

That sounds easier than it was. Prior to their completion, the trusses were very susceptible to buffeting winds. Work was halted when the gusts topped 36 mph, so construction moved at about 60 percent of normal pace. Despite the winds and the earthquake, work proceeded rather smoothly and the final truss bolt was tightened on schedule in September 1996. Painting, paving, and other miscellaneous work has also proceeded as planned. And all signals are go for the April 5 grand opening.

Longer suspension bridges are being proposed to connect Sicily and Italy, and to cross the Straits of Gibraltar. But neither these nor other proposed long-suspension spans seem likely to be constructed in the near future. This will likely leave the Akashi Kaikyo Bridge holding the crown as the world's longest suspension bridge for years to come. ◆

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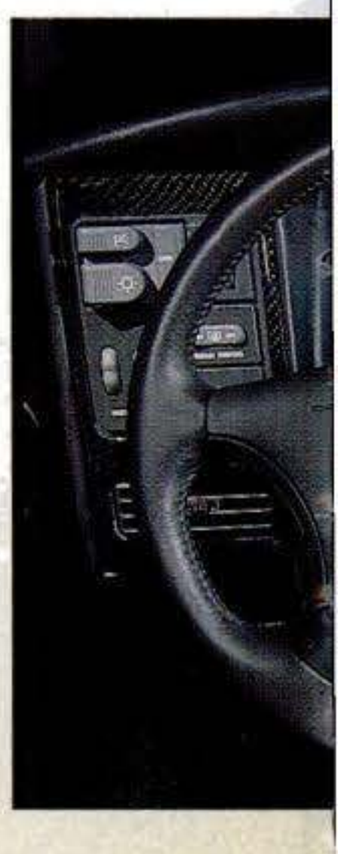
WIRED Wheels

A new "network vehicle" lets you check e-mail while driving, as your passengers browse the Web and watch TV.



By Suzanne Kantra Kirschner

TODAY'S MODERN CARS have become a complex system of rolling electronics, mirroring the computer age we live in. But aside from your cellular phone, your car rarely communicates with the outside world—or with you. The era of automotive solitude is coming to a close, however.

Delco Electronics (a unit of GM), IBM, Netscape, and Sun have teamed up to create the world's best-connected car, dubbed the Network Vehicle. This demonstration car meshes the usual auto electronics with a host of audio, video, computer, phone, satellite, and GPS devices, all linked by a looping network within the car. You can't buy a Network Vehicle yet, but Delco and IBM predict you'll be able to purchase a car like it in three to seven years.

In the meantime, the Network Vehicle provides plenty of technological teasers. Once inside, a voice-recognition system lets you talk to your car, and allows your car to talk back to you. A satellite dish embedded in the car's roof and LCD screens built into the car seats provide both TV programs and Internet access. A cellular phone and a head-up display system let you communicate while driving. Your vehicle's own Web site and GPS system give you new control, navigational, and emergency options. And most components can work together with interesting results.

When something goes wrong in your Network Vehicle, for instance, it warns you with an audible message. You can then call a service center for help; the center can do a diagnostic check remotely and access your car's maintenance log. And if you get stuck or lost, they can dispatch help to your exact location by reading your GPS signals, or provide directions to the nearest gas station or hotel.

The Network Vehicle also lets you keep in touch while you drive. The head-up display alerts you to incoming calls or e-mail messages by projecting icons that appear to be visible beyond the car's hood—where your eyes would be anyway. You can vocalize your wish to answer the call or have the e-mail read to you aloud. The navigation system is also linked into the head-up display, projecting turn-by-turn instructions. And the voice recognition system lets you dial the phone, select a radio station, or retrieve traffic updates, stock quotes, and news via the Internet.

You can customize your drive time, too. A docking station for IBM's WorkPad handheld computer (similar to 3Com's Pilot) enables you to download your schedule into the car for better route planning. And the navigation system can keep a mileage log for easier expense reporting. Passengers won't get bored, either. They can watch pay-per-view movies and standard TV fare via the DirecTV satellite service, or use the touch-screen color LCDs to surf the Web using its companion high-speed Internet service, DirecPC.

Some of the Network Vehicle's most tantalizing aspects stem from the fact that it's essentially a mobile Internet server with its own Web address. Amenities such as radio presets, seat position, and cellular phone numbers can be programmed while sitting at a computer. More importantly, perhaps, you can use the Internet connection to remotely lock your car, turn off the lights, or even shut off the engine if the vehicle's been stolen.

The Network Vehicle won't be alone on the high-tech highways. Clarion and Intel have less elaborate computer car systems that should be available later this year. ◆

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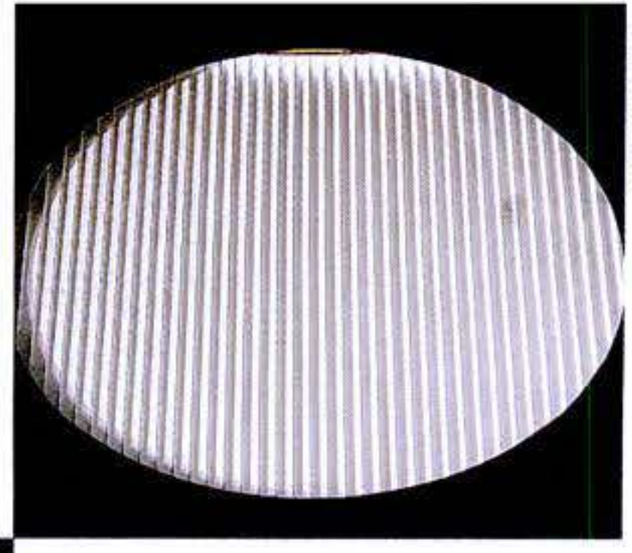
This touchscreen LCD lets you control nearly all vehicle systems and services from five categories: entertainment, navigation, office, Web site, and information. Depending on the mode, the console becomes a cellular phone, a CD player, a navigation system (shown), an Internet radio, or a climate-control panel, among others.



JIM FRENAK (3)

Protruding a scant 2 to 3 inches from the roof of the vehicle, the flat onboard satellite dish can pick up a signal from any angle. You can connect to the Internet at high speeds via the DirecPC satellite data service, with the uplink provided by a radio-frequency modem. Movies and other audio and video programming are beamed in from DirecTV satellites.

Touchscreens to the side of the passenger displays enable you to quickly navigate through services. You can type on a wireless keyboard.

From any passenger display, you can access a host of entertainment and information services, including DVD movies, audio-on-demand from DirecTV, and Web sites.

Satellite dish
Seat-occupancy sensor
Head-up display
PDA
GPS receiver
Center control display
Amplifiers/speakers
Cellphone antenna
DVD/CD player
Passenger displays
Door lock/door ajar
Road-speed sensor

Audio/Video Network: Fiber-optic cable transports audio and video data through the network at 250- to 1,000Kbps.

Network Computer: Central processing point for all networks. Uses Java to communicate with hardware via Ethernet and serial buses.

Car Electronics Network: Tracks and communicates all information from car electronics systems.

INFOGRAPHIC BY SLIM FILMS

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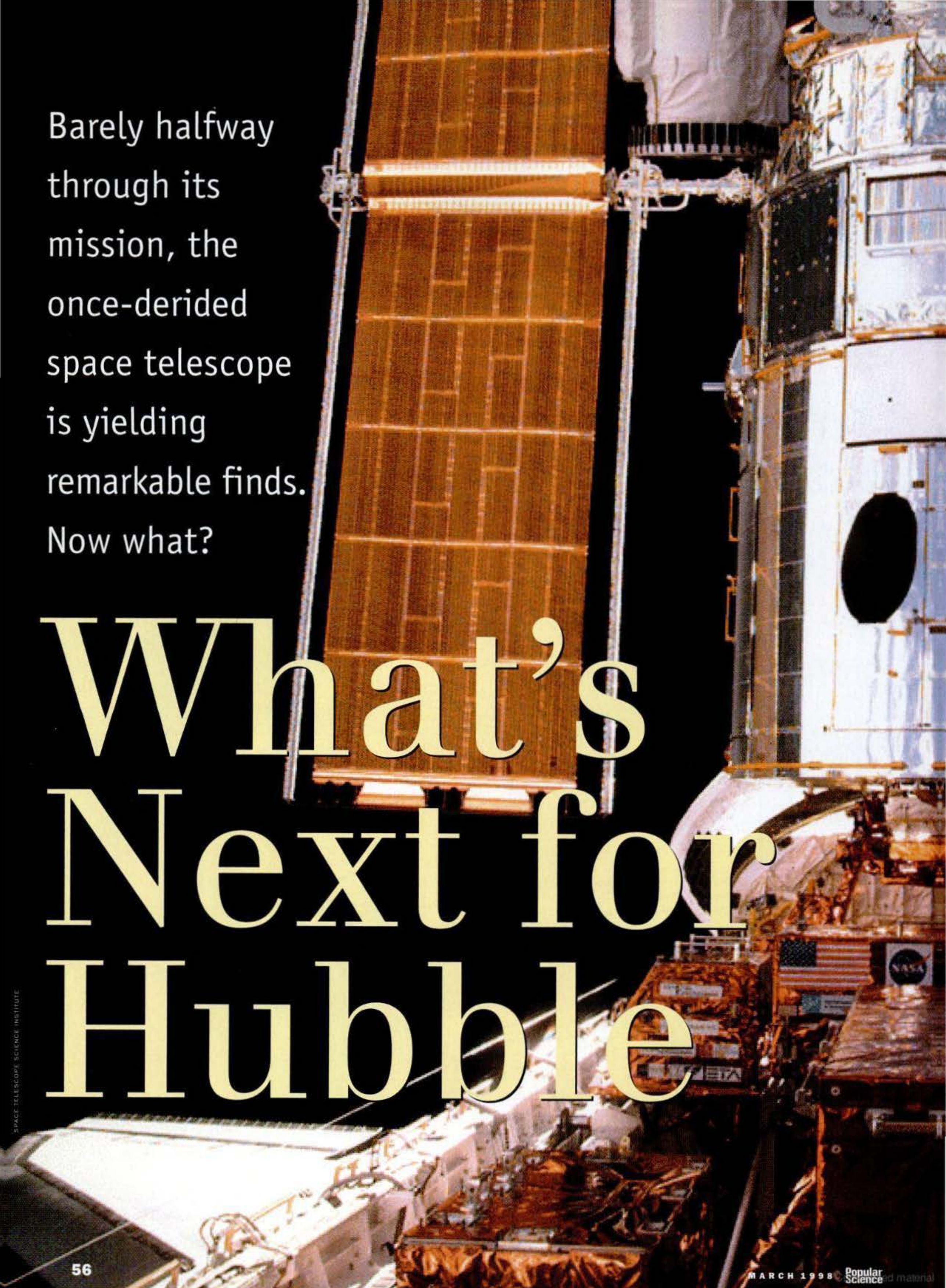
Barely halfway through its mission, the once-derided space telescope is yielding remarkable finds. Now what?

What's Next for Hubble



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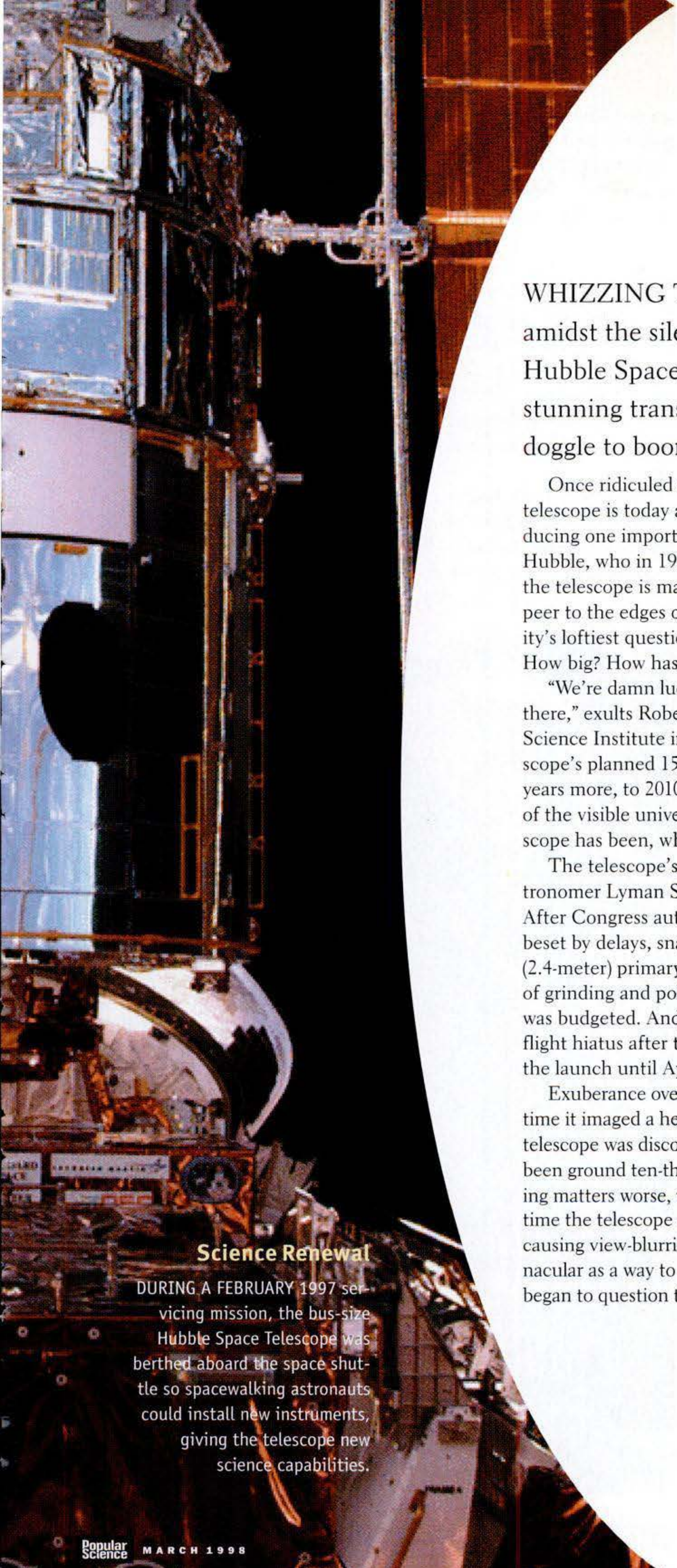

Science Renewal

DURING A FEBRUARY 1997 servicing mission, the bus-size Hubble Space Telescope was berthed aboard the space shuttle so spacewalking astronauts could install new instruments, giving the telescope new science capabilities.

By Mariette DiChristina

WHIZZING THROUGH its orbit at 17,500 mph amidst the silence of space, perhaps only the Hubble Space Telescope has been unaware of its stunning transformation from astronomy boondoggle to boon during its eight-year life.

Once ridiculed as a nearsighted "techno-turkey," the $3 billion telescope is today a sought-after tool for astronomers that is producing one important find after another. Named after Edwin Hubble, who in 1929 discovered the expansion of the universe, the telescope is making remarkable progress toward its goals: to peer to the edges of the cosmos and help answer some of humanity's loftiest questions. Among them: How old is the universe? How big? How has it evolved?

"We're damn lucky—we're blessed—to have that sucker up there," exults Robert Williams, the director of the Space Telescope Science Institute in Baltimore. In a vote of confidence, the telescope's planned 15-year mission was recently extended at least five years more, to 2010. As the Hubble continues to peek at the edges of the visible universe, it's time to take a look at where the telescope has been, what it has accomplished, and what lies ahead.

The telescope's story begins in 1946, when Princeton astronomer Lyman Spitzer proposed an American space telescope. After Congress authorized the program in 1977, however, it was beset by delays, snafus, and cost overruns. When the 94.5-inch (2.4-meter) primary mirror was completed in 1981—after five years of grinding and polishing—it cost $3 million more to make than was budgeted. And various glitches and the three-year shuttle-flight hiatus after the tragic loss of the Challenger in 1986 delayed the launch until April 24, 1990.

Exuberance over the telescope's successful "first light"—the first time it imaged a heavenly body—soon turned to anguish when the telescope was discovered to be nearsighted. The primary mirror had been ground ten-thousandths of an inch too flat at the edges. Making matters worse, the solar panels flexed every 90 minutes—each time the telescope crossed the line that separates night and day—causing view-blurring jitter. "To Hubble something" entered the vernacular as a way to describe a colossal foul-up, and critics even began to question the continued existence of NASA.

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Three years later, a dramatic $250 million, 11-day repair tuned up the ailing telescope. Astronauts installed corrective optics ("eyeglasses"); less flexible solar arrays to stop the jitter; an upgraded camera for better images of star fields and planets; and more.

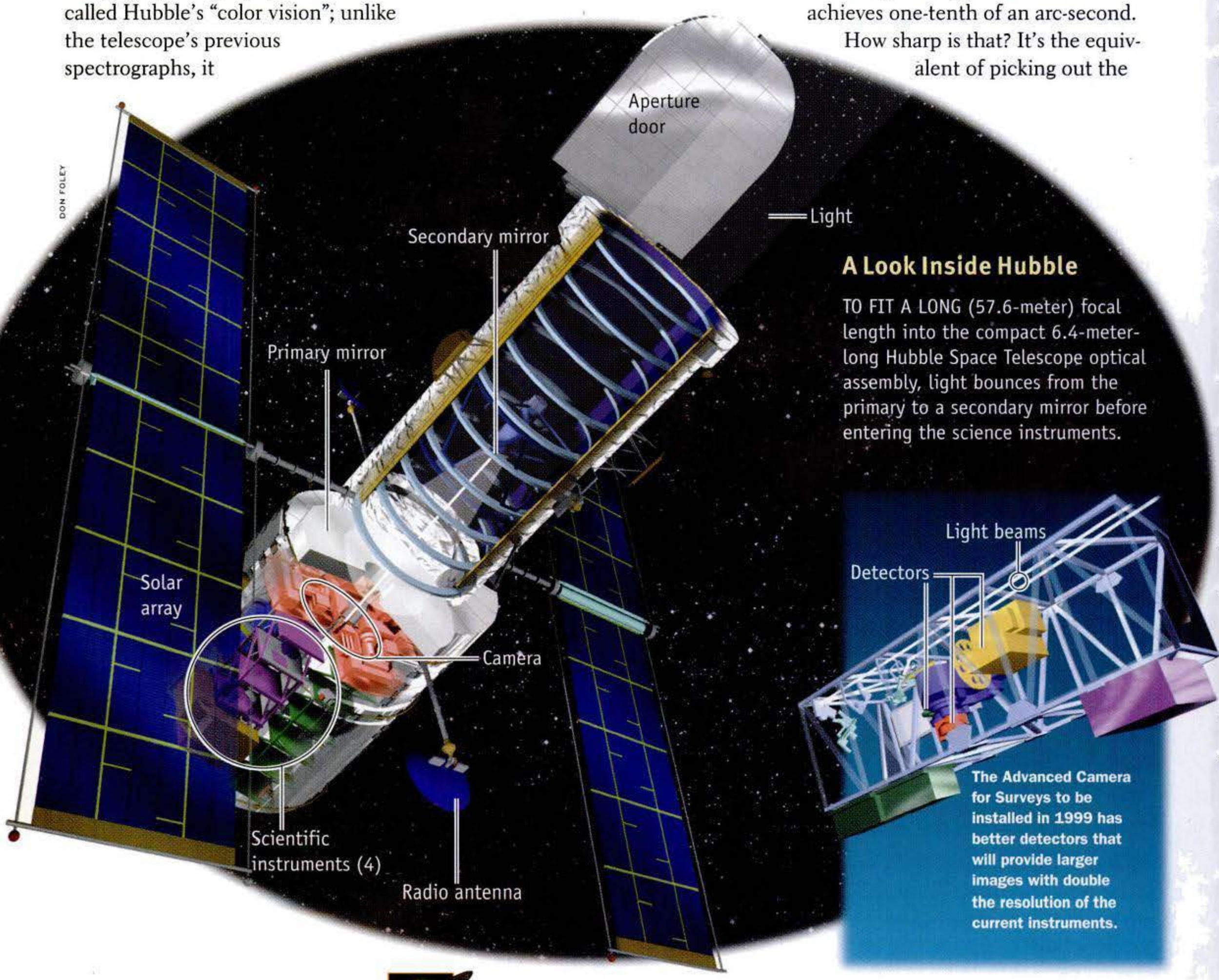
NASA followed up with a second, $350 million servicing mission in February 1997. Astronauts also installed two instruments new to the Hubble that increased the telescope's data-gathering power by a factor of ten. One is the Near-Infrared Camera and Multi-Object Spectrometer, which extended the telescope's capability into the infrared light wavelengths, longer than the red light humans can see in the electromagnetic spectrum. The second, the Space Telescope Imaging Spectrograph, has been called Hubble's "color vision"; unlike the telescope's previous spectrographs, it can look at many—up to 512—different areas or objects in space at once, to learn clues about their composition, speed, and temperature.

To upgrade the storage capacity to handle this new data, astronauts replaced a tape data recorder with a solid-state version. And in contrast to earlier technologies, the new instruments have built-in intelligence so they can work together, and work with another camera already aboard the telescope. Imaging simultaneously in different wavelengths gives astronomers a better understanding of an object.

With the Hubble's new instruments, "It'll look in the infrared and see a different universe. To look 10 billion years ago, you have to look at the infrared," says Williams. And in the infrared is where the Next Generation Space Telescope, the successor to the Hubble, will specialize. (See "The Space Telescope of the New Millennium," page 60.) "Looking at the stuff from billions of years ago—that's the stuff out of which we were formed," he says. "Astronomy seeks answers to life's most profound questions, such as: Where did we come from? Where are we headed?"

The Hubble is poised to help answer such questions from its vantage point in orbit above Earth. Peering through the haze of our planet's atmosphere, ground-based telescopes can resolve an image to about one arc-second (equal to $1/3{,}600$ of one degree in the 360-degree "pie" that makes up the sky). The Hubble achieves one-tenth of an arc-second.

How sharp is that? It's the equivalent of picking out the



DON FOLEY

A Look Inside Hubble

TO FIT A LONG (57.6-meter) focal length into the compact 6.4-meter-long Hubble Space Telescope optical assembly, light bounces from the primary to a secondary mirror before entering the science instruments.

The Advanced Camera for Surveys to be installed in 1999 has better detectors that will provide larger images with double the resolution of the current instruments.

Links to the best Hubble sites www.popsci.com

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individual lights of two fireflies sitting atop the palms of a person with outstretched arms in Tokyo, from a vantage point in New York.

"I believe the great legacy of the Hubble will be the clear view it gives us of the distant universe," says Williams. "A century or two from now, that will be the essential thing we got from the Hubble."

Looking deep into space, the Hubble is helping astronomers learn about the universe's expansion rate, and what may be its eventual fate. Researchers are zeroing in on the Hubble constant, a critical mathematical figure devised by Edwin Hubble in 1929 that will reveal how fast the universe is expanding, by using the telescope to locate special stars called Cepheid variables, as well as distant supernovae. These bodies can be used as yardsticks to measure the vastness of space. If there is enough mass, the so-called critical mass, and expansion slows over time, a theory goes, eventually the universe could recollapse for another Big Bang. The universe would then begin again.

According to Williams, however, telescope data indicates that the expansion is not really slowing down. "The universe may coast to infinity," he says. As it continues to expand, stars would burn out over the eons, and the universe would come to a brutally cold, black end. That finding is surprising to many astronomers, who favor the idea that the universe would continue in some fashion.

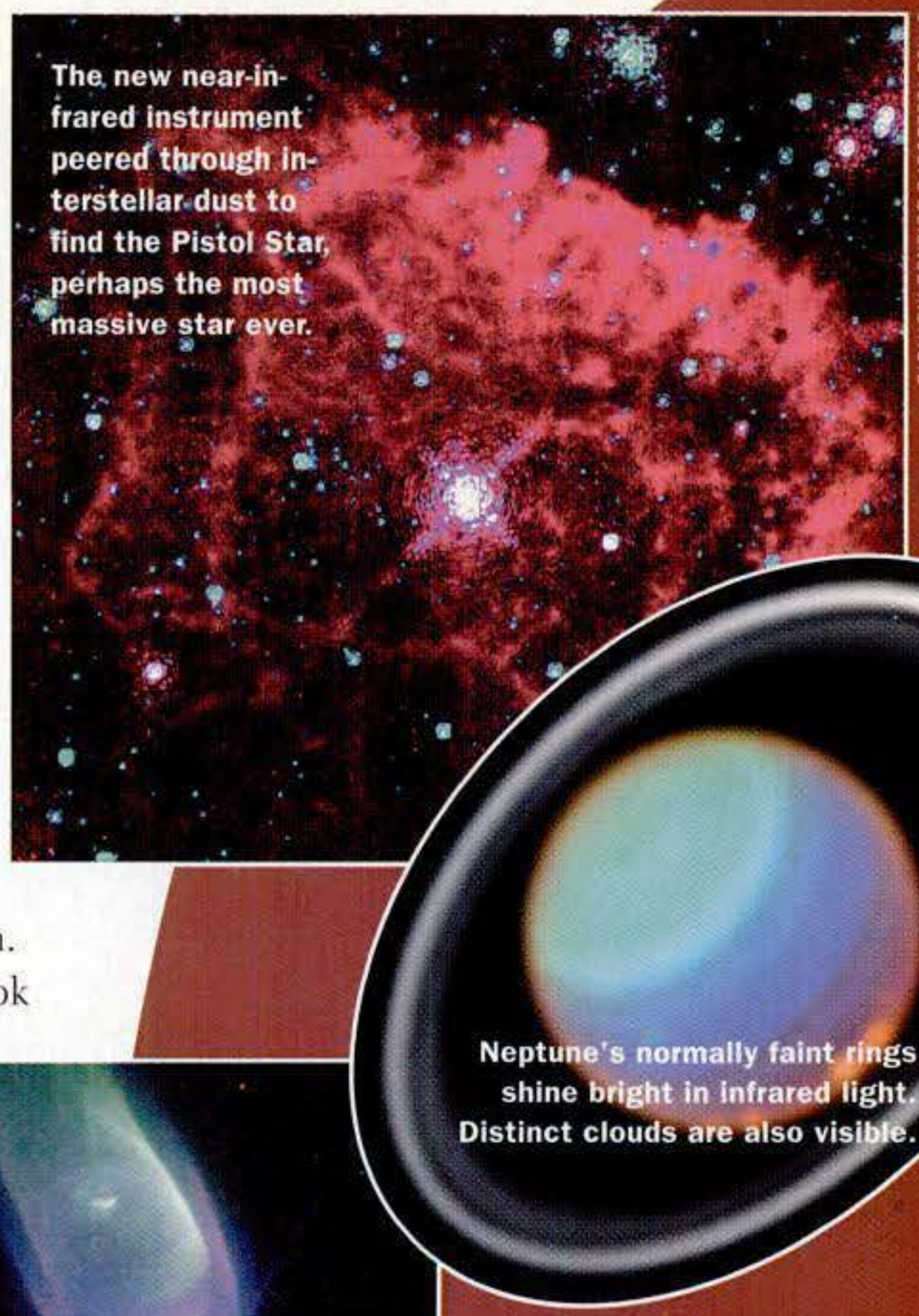
In other Hubble achievements, the telescope has been able to detect the chemical composition and nature of stellar objects in nearby galaxies. The telescope also has a unique ability to view the universe in ultraviolet, which is not possible with ground-based telescopes because such light is largely blocked by Earth's atmosphere. Some hot, young stars are more visible in ultraviolet, for example.

Closer to home, the telescope probes our planetary neighborhood. Unlike single missions such as the famously successful Galileo probe of the planet Jupiter, the Hubble can study objects night after night. For example, it watched while the fragments of Comet Shoemaker-Levy 9 blasted the big planet, and imaged volcanoes on the Jovian moon Io.

With these enhanced capabilities, is there anything the Hubble *can't* detect? "Extraterrestrial intelligence," snorts Williams. "That's one thing the Hubble will never find."

Kidding aside, Williams hopes that the Hubble's mission will be expanded to include a new kind of investigation. A few years back, the Hubble took a view, or survey, deep into space. Known as the Hubble Deep Field, this striking survey turned up more than 3,000 distant galaxies and helped determine how star formation in the universe has evolved over time. The equivalent of fishing expeditions, surveys could find as-yet-unsuspected phenomena. "I believe that is the most likely area in which the Hubble could revolutionize our view of the distant universe," says Williams.

One instrument ideally suited for what Williams envisions is the Advanced Camera for Surveys. The camera is slated to fly to the Hubble on its next servicing mission, scheduled to launch in December 1999. The camera, which will replace the 1970s-era Faint Object Camera, will have larger detectors, for a larger view of the sky. It also will offer twice the detail that is now possible with current instruments. The '99



The new near-infrared instrument peered through interstellar dust to find the Pistol Star, perhaps the most massive star ever.

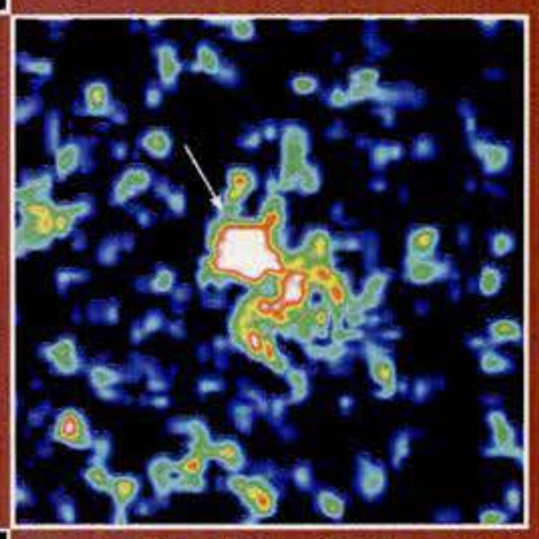
SPACE TELESCOPE SCIENCE INSTITUTE

Neptune's normally faint rings shine bright in infrared light. Distinct clouds are also visible.

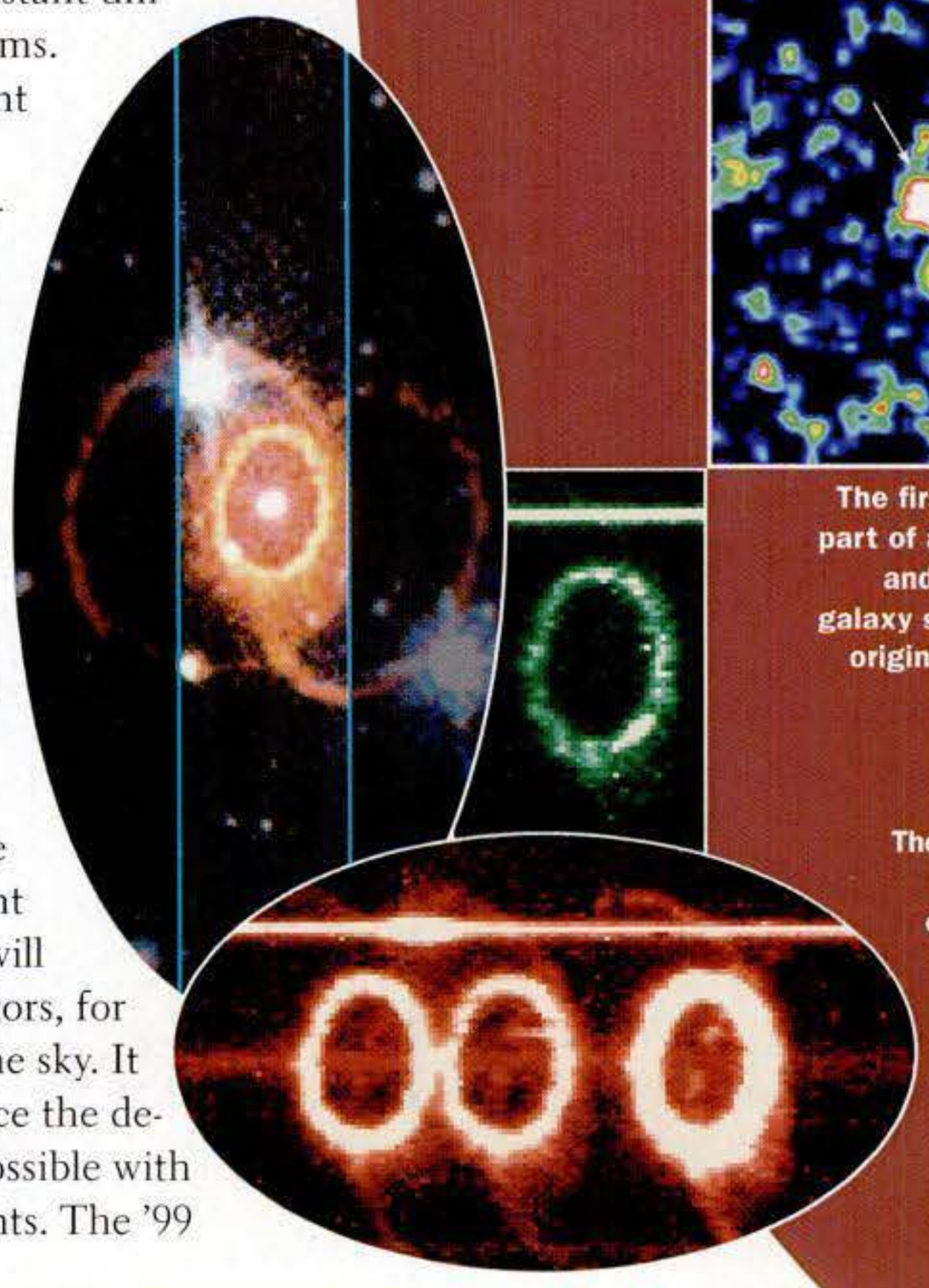
The Wide-Field and Planetary Camera captured the roiling jet-like exhausts from a dying star.

Hubble Science

IN THE past year, the Hubble has churned out a gallery of finds, many with the help of two new instruments installed during the 1997 servicing mission.



The first optical counterpart of a gamma-ray burst and its potential host galaxy suggests a cosmic origin for these puzzling energy releases.



The new spectrograph reveals chemical components around supernova 1987A, including oxygen (single green ring) and nitrogen and hydrogen (triple orange rings).

More stunning shots taken by Hubble www.popsci.com

The Space Telescope of the New Millennium

THE HUBBLE SPACE TELESCOPE will orbit Earth for at least another dozen years, but plans are already on the drawing board for its successor, which will be called the Next Generation Space Telescope.

The NGST, as it is known, will pick up where the Hubble leaves off in the search for knowledge about the early evolution of the universe, when it was between 100 million and 1 billion years old. "The NGST has as a primary science goal the study of the very early universe," says Harlan Thronson, deputy program scientist for the Hubble at NASA headquarters in Washington, D.C. "The Hubble can look to objects back to 10 to 20 percent of the current age of the universe," says Thronson. "The NGST will look back to a fraction of a percent. It should see galaxies as they form."

While the Hubble specializes in examining the cosmos in the shorter wavelengths of ultraviolet and visible light, the NGST will delve into the universe at the longer infrared area of the electromagnetic spectrum. Because galaxies are moving away from ours as the universe expands, their light is shifted to the longer red wavelengths—it reaches Earth at infrared wavelengths.

To do this, the NGST will be larger than the Hubble, which has a 2.4-meter primary mirror. The new telescope will have a 6- or 8-meter mirror. It will have a larger aperture—two to four times that of the Hubble, for four to 16 times greater collecting area. "Because the NGST is working at longer wavelengths, it will have an approximately similar clarity of view as the Hubble," adds Thronson.

There will be other differences as well. The NGST will not circle Earth, but occupy a stable orbit between our planet and the sun about 1.5 million kilometers distant, past the moon. And while the $3 billion Hubble embodies the old "big science" thinking, the NGST has been conceived under NASA's current goal of "faster, better, cheaper" missions. The entire development of the telescope is targeted for $500 million, with $400 million more expected over its planned 10-year lifetime.

"It's expensive to maintain the Hubble, and to make systems [for the telescope] that can be pulled out. It's expensive to train astronauts for servicing missions," says Thronson. "The downside [for the NGST], of course, is that if a catastrophic problem occurs, you would not be able to service it as with the Hubble."

Not orbiting Earth has advantages for science as well. "The NGST has to be very cold to work in those infrared wavelengths," says Thronson. Too much heat degrades the performance of the sensitive detectors, which will be cryogenically cooled. The NGST is expected to be 1,000 times more sensitive than any existing or planned ground or space telescope. "We don't want energy from the instruments [or Earth sources] to overwhelm the faint objects," adds Thronson.

There are four competing NGST designs, from Ball Aerospace & Technologies Corp. of Boulder, Colorado; Lockheed Martin Corp. of Bethesda, Maryland; TRW Space and Electronics Group of Redondo Beach, California; and Goddard Space Flight Center of Beltsville, Maryland. Three of the designs feature foldable parts, so the telescope could fit aboard an Atlas-class or other expendable launch rocket.

The decision about which design to pursue would likely be made around 2002, so construction could begin the following year, says Thronson. The NGST weight goal is 3,000 kilograms (compared with 11,000 for the Hubble), so creating its large, lightweight mirrors will require breakthrough materials advances. Some of the designs also borrow inspiration from military satellites, says Thronson.

Like the Hubble, the NGST may have international partners. In preliminary funding discussions, the European Space Agency, a 15 percent partner in the successful Hubble, has expressed interest in contributing to the NGST around that percentage. Canada is also considering joining the project, perhaps at the 5 percent level.

If all goes as planned, the NGST will launch in 2007. With the Hubble mission recently extended to 2010, two space telescopes could be plying the skies together for three years. "The two in tandem will be a real one-two punch," says Dave Leckrone of the Goddard Space Flight Center.—*M.D.*

One of four competing designs for the Next Generation Space Telescope, this concept by Ball Aerospace would use 32 segments to make up an 8-meter mirror. The sunshades and secondary mirror would fold to fit aboard a launch rocket.

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mission, and another in August 2002, will again upgrade the telescope's capabilities and shore it up against deterioration as it is pelted by micrometorites and exposed to the extreme conditions of space.

The '99 mission will be a major overhaul. "It's like the 60,000-mile tune-up," says Chris Blades of the Space Telescope Science Institute. But NASA isn't taking any chances that instruments for the overhaul mission will fail. During a 10-day shuttle flight scheduled to launch in early October, astronauts will test some components for the '99 mission. One will be a mechanical cryocooler. "We'll put it through its paces to see if it's going to do what we think it's going to do," says Frank Cepollina, project manager of the telescope servicing project at Goddard Space Flight Center in Greenbelt, Maryland. The device is intended to cool the near-infrared camera installed last February; a failure in the protective, thermos-like dewar has halved the intended four-year life of the instrument.

In addition to the cryocooler, astronauts in '99 will install a system to cool the telescope's aft shroud. Heat is slowly becoming a problem, as using cameras simultaneously—a scientific advantage—is warming the Hubble; that degrades the performance of its sensitive detectors.

Also on the checklist are a second solid-state data recorder, improved insulation to replace the degrading material now protecting the telescope, a new central computer, new solar panels, and finally, a reboost of the telescope itself, which has sagged in orbit 20 miles since a reboost performed in 1993. "The more I think about '99, the more I think that'll be a heck of a mission," says Blades. "I mean, you've tested it all like mad in the lab, but you don't know."

That uncertainty doesn't keep scientists from planning for the future, however. In 2002, the Hubble team plans to enhance the telescope's science capabilities again with the Cosmic Origins Spectrograph, which likely will replace the Hubble's eyeglasses, since all new instruments include their own corrective optics. It will complement the spectrograph installed last year, and will be more sensitive to the very faintest objects in the sky. In fact, it will be 15 to 20 times more sensitive than any other Hubble spectrograph.

To make the most of the two final missions—and because funds will not likely be allocated for another—researchers are also getting creative, says David Leckrone, senior scientist for the telescope at Goddard. "The chances of having another servicing mission are remote, though you never want to say never," says Leckrone.

With careful planning, and perhaps using spare parts and the old Hubble instruments brought back to Earth on the shuttle, some new options could be developed for the telescope. For example, researchers are planning a second detector channel for the Comic Origins Spectrograph, so it can also serve as a backup if another instrument fails. Also on the drawing board is the idea of refurbishing the first Wide-Field and Planetary Camera, which was removed in '93, with new detectors and flying it again in 2002. It could serve as a backup for the other cameras. "We're turning over everything in the Hubble budget to do these things," adds Leckrone.

Indeed, in the current NASA world view of "faster, better, cheaper" missions, a costly and complex "big science" project like the Hubble is like a leopard trying—and in some ways succeeding—to change its spots.

Some astronomers have accused the Hubble's costly operations of sapping funds that could be used for other projects. But it's cheaper, argues Cepollina, to service the telescope than to design, build, and fly separate, entirely new missions. "The Hubble's most significant message is that it can allow for the economic progression of science results without having to rebuild and start from scratch again and again," he says.

The challenges wrought by the number and length of space walks for each Hubble servicing mission have also expanded NASA's knowledge about how humans can work in space, which will prove useful in the construction of the International Space Station. "Each [mission] has pushed the envelope a little bit more," adds Cepollina.

In any case, space observatories like the Hubble will never replace Earth-bound telescopes, but instead are intended to complement them. "The Hubble is most powerful when its imaging is used in conjunction with ground-based telescopes," says Williams. One recent example was when the Hubble imaged the optical counterpart of a gamma-ray burst located by radio astronomy. Astronomers learned for the first time that these puzzling bursts of extraordinary energy are likely cosmic in origin, not from our galaxy.

And while the space telescope found many faint galaxies in the Hubble Deep Field survey, determining their age is a task better suited to the 10-meter Keck telescope in Hawaii. "When you really want to gather light for the faintest objects, a 'light bucket' like the Keck is better," says Williams. That's because, for all the crispness of its resolution, the Hubble's 2.4-meter primary mirror makes it a fairly small telescope.

So what awaits the Hubble at the end of its planned life? "The long-range fate of the Hubble is under consideration," says Harlan Thronson, the deputy program scientist for the Hubble at NASA headquarters in Washington, D.C. "Bringing it back to Earth [via the shuttle] or having a controlled reentry so it would land in the Pacific are both possibilities." The decision about Hubble's fate should be made sometime in the middle of the next decade.

"The year 2010 is a placeholder, intended to mean the far future," adds Thronson. "There are no plans to terminate the Hubble." ◆

Hubble's past, stories from our archives www.popsci.com

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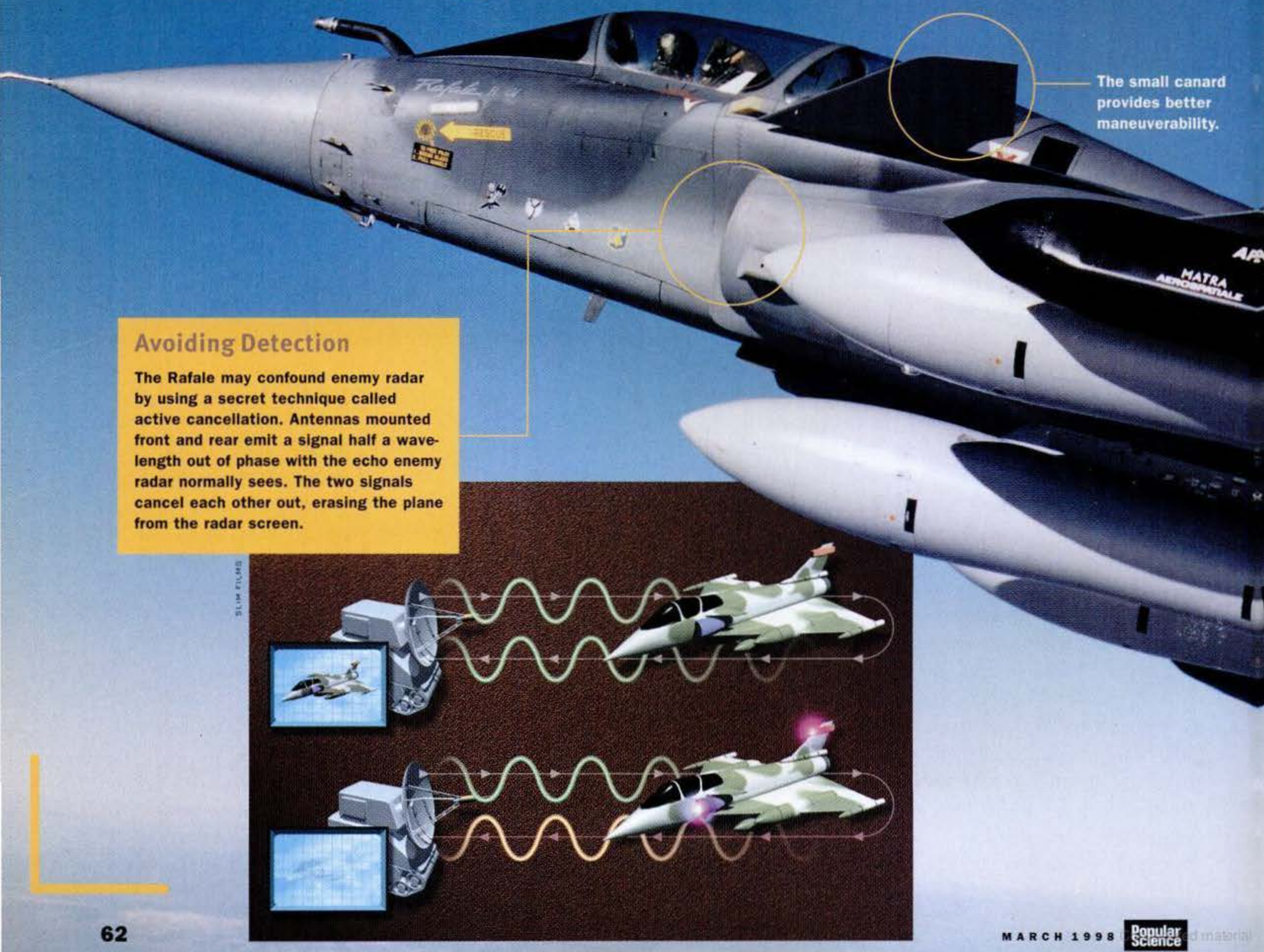
A Plane for Land Sea and

Agile and stealthy, France's Rafale may be the most versatile aircraft in the sky.

By Bill Sweetman



Avoiding Detection

The Rafale may confound enemy radar by using a secret technique called active cancellation. Antennas mounted front and rear emit a signal half a wavelength out of phase with the echo enemy radar normally sees. The two signals cancel each other out, erasing the plane from the radar screen.

SLIM FILMS

FRANCE'S DASSAULT company designs and builds more supersonic fighters than anyone outside the United States or Russia. But its delta-winged Mirages are often dismissed as fast, flashy machines that look good in the independence-day flyby but are mainly useful for making sonic booms.

Bastille Day is about to get a whole new look. France's new Rafale is different. In fact, it may be the most versatile fighter available today, and some of its features will not be matched until the Pentagon's new Joint Strike Fighter enters service, around 2010.

The Rafale was designed to meet a unique requirement: The French air force and carrier-based navy want one airplane to replace almost all of their combat aircraft. Dassault chose a broad, efficient delta wing with plenty of space to carry weapons and fuel, and added a small canard, placed just ahead of the wing, for agility. The canard boosts the lift over the wing and reduces the fighter's approach speed for carrier landings.

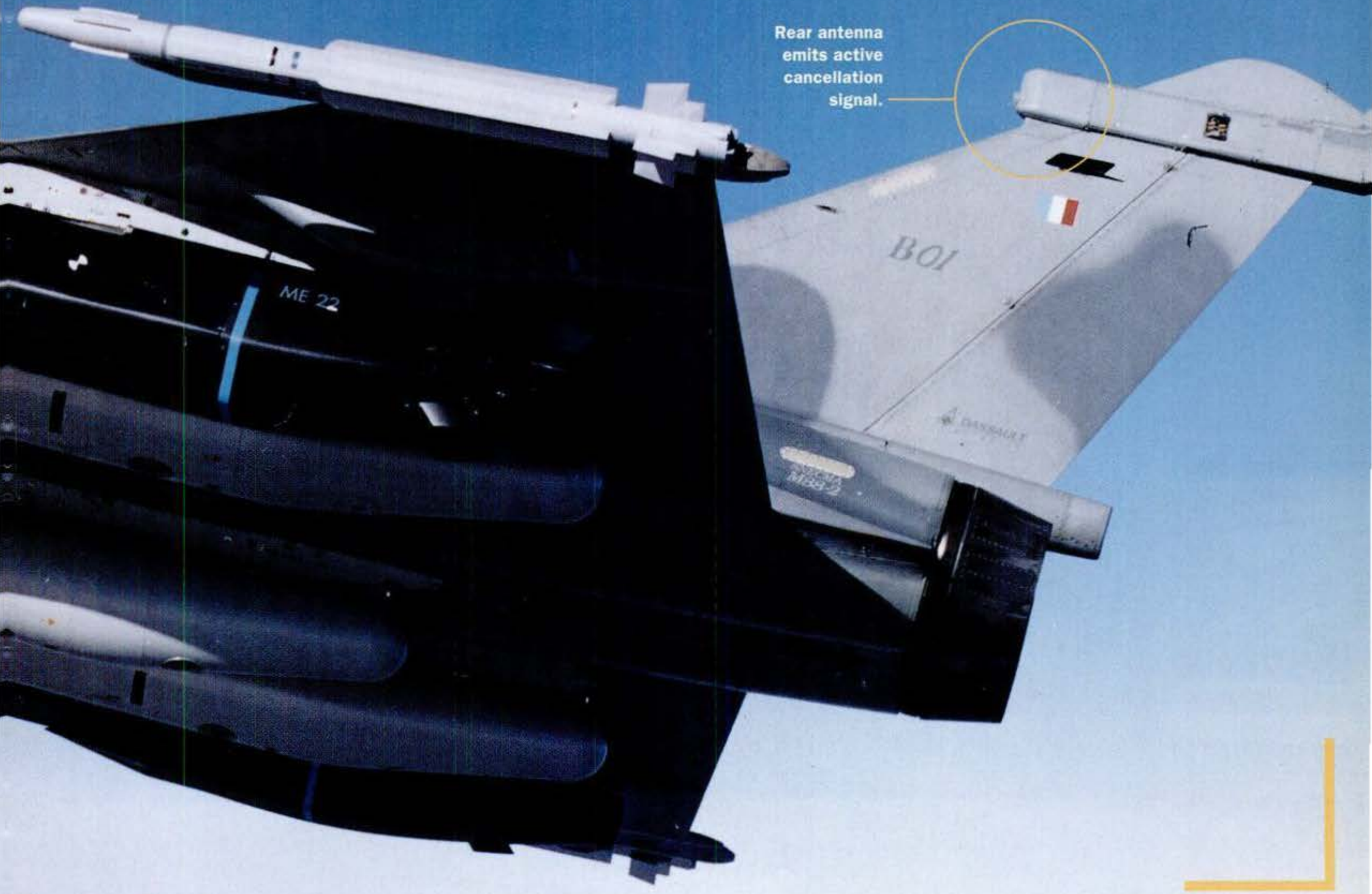
The twin-engine, almost all-composite Rafale is bigger than an F-16, but lighter than the U.S. Navy's F/A-18 Hornet. The Rafale can carry an 8-ton load—nearly equal to its own weight. According to Dassault, the Rafale can carry 6,000 pounds of weapons almost 700 miles and return without refueling—better than any other Western fighter except the much bigger F-15E.

The Rafale has another, stealthier edge. Since the Rafale is too small to carry its weapons internally, stealth technology gets used differently than in U.S. fighters. The Rafale's sloped body sides and smooth surfaces, combined with saw-toothed radar-absorbent appliqués, are designed to make a electronic warfare system called Spectra more effective.

Spectra is designed to locate and jam enemy radar automatically. One of Spectra's designers hints at "stealthy jamming modes that make the aircraft invisible." This sounds a lot like active cancellation—a technique in which an airplane transmits a duplicate of the echo that a radar would normally detect, but half a wavelength out of phase, so the radar sees nothing. Active cancellation is not easy to do; if it is used on any U.S. military aircraft, the fact is highly classified.

The Rafale uses special Matra MICA air-to-air missiles that can be deployed against both close and distant targets. Aiming the missiles is one of the functions of the Imperial Trooper-style pilot's helmet, which combines the targeting display, oxygen mask, and chemical-warfare protection in one unit that actually weighs less than today's standard "bone-dome" helmet.

Initiated only a few months ahead of the rival Eurofighter being built by Britain, Germany, Italy, and Spain, the Rafale flew four years before the Eurofighter's 2001 target. However, it has suffered from funding cuts: France does not plan to field the first squadron until 2005.



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Computing's OUTER LIMITS

Microprocessors are bumping up against some fundamental barriers to speed and power. Can future chips leap these hurdles and keep the electronic miracles coming?

ILLUSTRATION BY ERIC YANG

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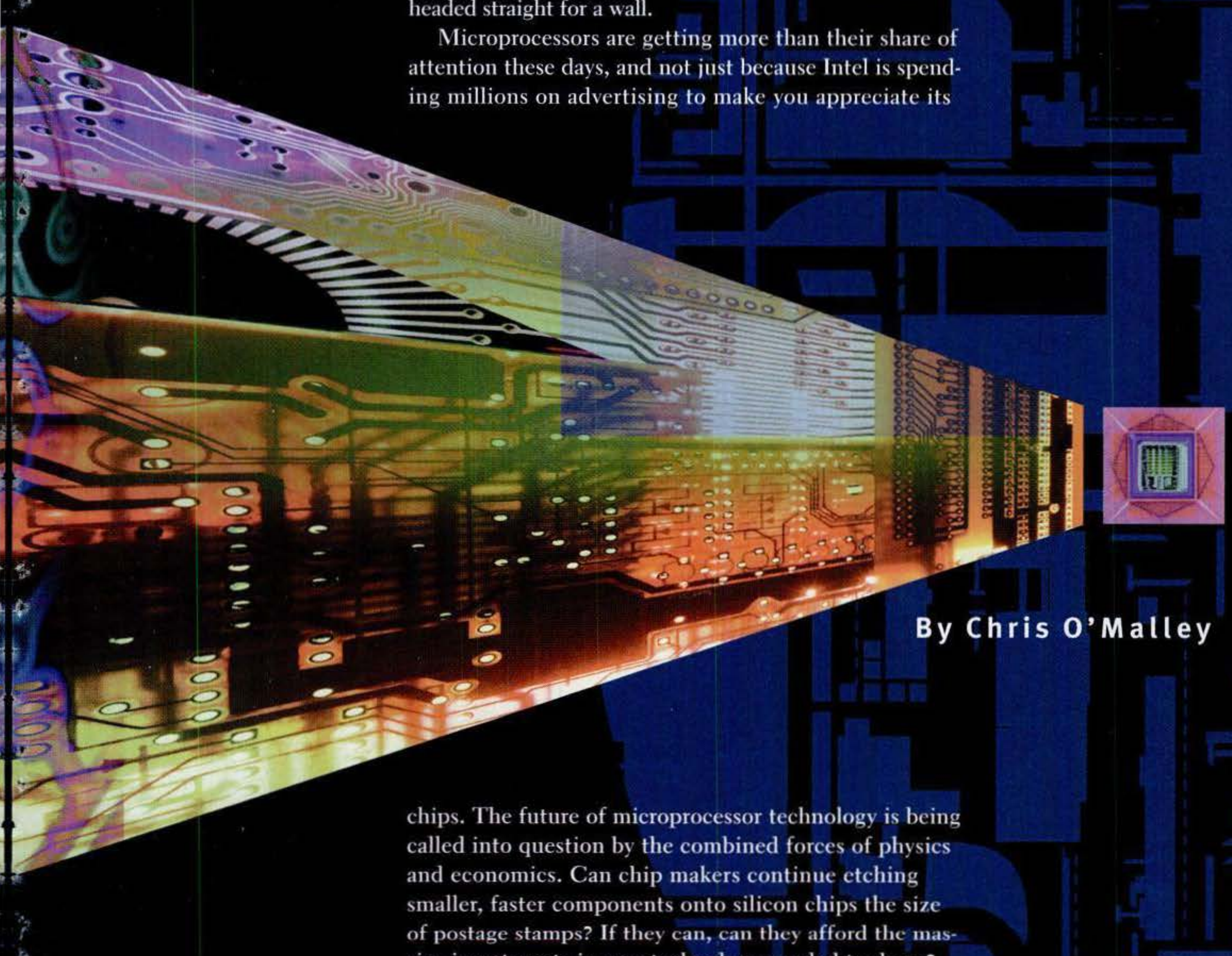
THEY ARE THE largely hidden engines of the information age, the driving forces behind today's computers and tomorrow's digital televisions, stereos, appliances, and unimagined gadgets. Improvements in their technology occur with such breakneck regularity that a generation may last only a year or two. In the 1990s, they're speeding along even faster than the experts had expected. And they may be headed straight for a wall.

Microprocessors are getting more than their share of attention these days, and not just because Intel is spending millions on advertising to make you appreciate its



By Chris O'Malley

chips. The future of microprocessor technology is being called into question by the combined forces of physics and economics. Can chip makers continue etching smaller, faster components onto silicon chips the size of postage stamps? If they can, can they afford the massive investments in new technology needed to do so? And can consumers afford the results?

These are relevant questions for all types of semiconductors, including memory chips and more specialized integrated circuits. But the issues are most urgent for microprocessors, which are the brains of virtually all electronic devices. These modern marvels of miniaturization pack millions of tiny transistors—electrical

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on/off switches that calculate the ones and zeros of computer instructions—into silicon wafers. They are the ultimate semiconductors, though there's been nothing "semi" about their pervasive impact on our lives. By one estimate, there are 200 *quadrillion* transistors in use each day, or about 40 million for every man, woman, and child on the planet. By another reckoning, every year chip makers are shipping nearly as many transistors as Earth has ants (10 to the 17th power).

Since Intel brought the first microprocessor, the 4004, to market in 1971, chip makers have made dramatic advances in computing and electronics by faithfully upholding what came to be known as Moore's Law: that the number of transistors on a chip, and its resulting performance, doubles every 18 to 24 months. Intel cofounder Gordon Moore actually made that observation in 1965 about the capacity of memory chips, but it's held remarkably true for microprocessors. The number of transistors has mushroomed from 2,300 on the 4004 chip to 7.5 million on the Pentium II chip, for example. And their performance has grown exponentially, from executing 10,000 instructions per second to more than 25 million per second.

But in designing chips with such microscopic ingenuity, chip makers may soon find themselves actually unable to manufacture these wee wonders, or at least to make them economically. Moreover, transistors are becoming so small, and the wires between them so thin, chip designers head into the new millennium bumping up against the laws of physics. Wires already 400 times thinner than a human hair can be made skinnier yet, but the task of continually doubling the speed of electrons passing wires of near-zero width will be tricky—and maybe impossible at some point.

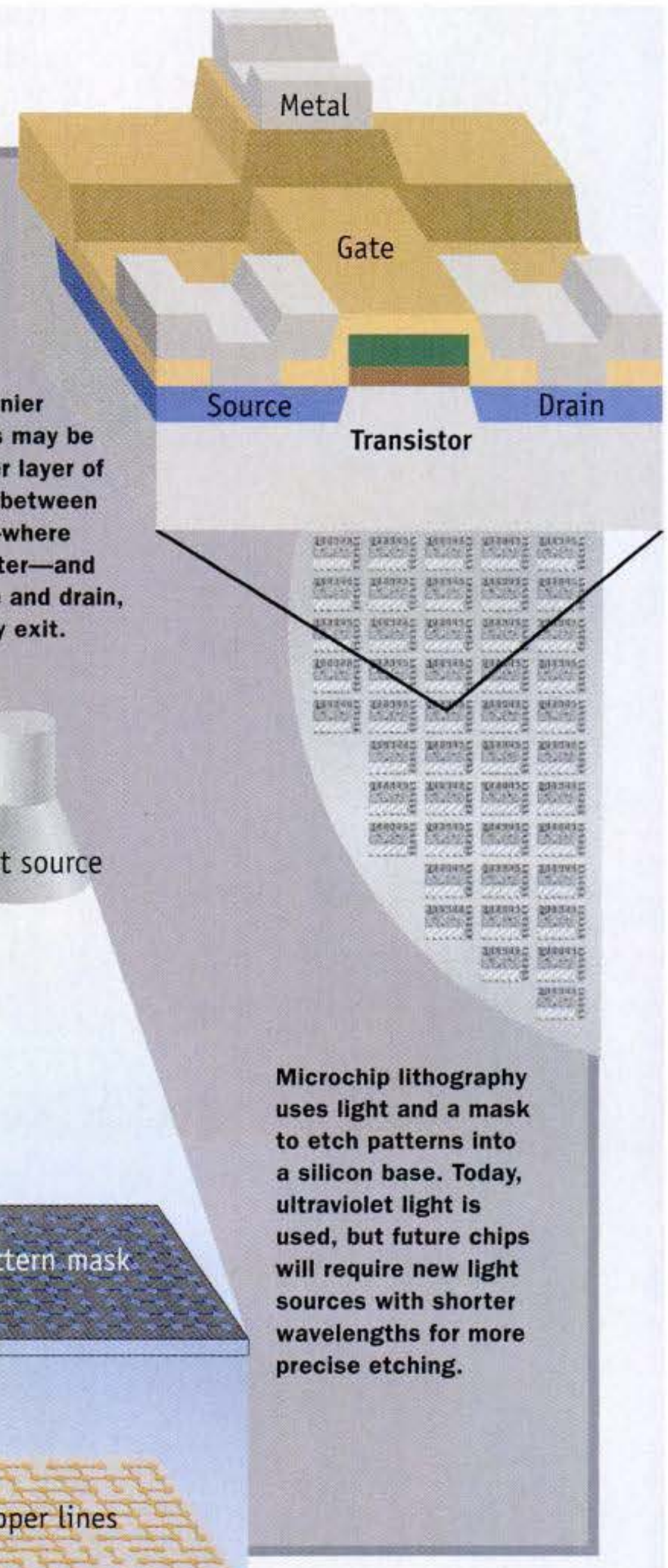
"Moore's Law can be sustained certainly for five years, and probably for 10 years," predicts Michael Slater, who is founder of the research firm MicroDesign Resources and editorial director of *Microprocessor Report*. "After that, things could slow down without new and different technologies."

Ironically, as microprocessors work their way into more aspects of our lives, there may be less demand (and payback) for cutting-edge chips, too. To make future digital TVs, 500-channel cable boxes, video phones, and other consumer appliances affordable, the processors will probably have to cost less than $100 apiece. New microprocessors tend to cost $500 to $1,000 each, sometimes more, and then slowly slide down the price scale. Even in PCs, the emerging trend toward low-cost computers, including so-called network computers and Internet TV devices, could dampen enthusiasm for expensive PCs with the latest chips. And while there is a clear and pressing need for more speed in the server computers and routers that connect PCs via the Internet and company networks, the need may be far less clear for the already pumped-up PCs of the year 2001. "The bottleneck is really in the network, not on the desktop," explains Garth Nash, a vice president in Motorola's network and computing systems group.

Still, microprocessors are hardly in danger of stalling over the next few years. Intel has new versions of its Pentium II chip running at speeds up to 450MHz on tap for this year, and an even more powerful microprocessor code-named Merced slated for 1999. IBM and Motorola

Chip Challenges

FOR MICROCHIPS to continue getting faster, chip designers will need to make transistors (right) smaller and the connecting lines between them thinner and better conductors. One key lies in finer methods of etching circuitry on silicon wafers, a process known as lithography (below). Another is the use of copper instead of aluminum in these patterns.



A key to tinier transistors may be in a thinner layer of insulation between the gate—where signals enter—and the source and drain, where they exit.

A thin layer of metal completes the transistors and adds the lines that link them. New chips will use copper, a faster conductor than aluminum.

Microchip lithography uses light and a mask to etch patterns into a silicon base. Today, ultraviolet light is used, but future chips will require new light sources with shorter wavelengths for more precise etching.

K. DANIEL CLARK

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may have a 500MHz PowerPC chip ready later this year, and they're working on a 1.1-gigahertz (about 1,100MHz) version. Sun Microsystems, meanwhile, says it is working on a chip for advanced workstation computers that will have an astonishing 30 to 40 million transistors, due by the year 2000.

But to keep up this pace of progress, or anything close to it, the superchips powering post-millennium devices will have to overcome a host of technical challenges. Indeed, a just-published technology roadmap by the Semiconductor Industry Association (SIA) reports that chip makers will need new techniques and materials by 2003, a startlingly close date given the years it often takes to develop and refine new technologies.

"There's a wall out there somewhere; it's just a matter of where and when," concedes Mark Bohr, director of process architecture and integration at Intel, the world's largest chip maker. "But we keep finding ways to go through walls."

Researchers are already hard at work attempting to do just that. Atop the to-do list of microprocessor breakthroughs is a more exacting method of laying the circuitry onto the silicon base of a chip that would permit smaller, more densely packed processors. Contrary to the outward appearances of ever-smaller electronic devices, microprocessors are not really getting smaller. They've actually grown larger, in up and down fashion, over the past 27 years. But they're not much larger, and the number of transistors they squeeze into a small silicon die has multiplied many times over. And the wires that connect them are on a crash diet; the wires in today's most advanced chips are a mere 0.25 microns wide. Within the next two to three years, that will step downward to between 0.18 and 0.13 microns.

Today's optical lithography method, which etches transistors into the silicon and prints a pattern of interconnecting wires by shining ultraviolet light through a mask, is adequate for these two chip generations. But wires as thin as 0.10 microns or less will likely require different types of masks and light sources with shorter wavelengths. Current lithography techniques are "running out of gas," says Mike Polcari, director of silicon technology for IBM Microelectronics. "With the right lithography," he adds, "we think we can scale devices down to the deep 0.10 microns."

Chip makers are already in hot pursuit of such mind-boggling microscopic circuitry. Intel, Motorola, and Advanced Micro Devices recently pledged $250 million to three Department of Energy labs working on "extreme ultraviolet" lithography techniques that are far more precise than today's UV method. IBM and others are investigating the use of X-rays. Researchers at Lucent's Bell Laboratories think they have an even better alternative. Their electronic beam lithography system, which projects high-energy electrons through a photomask, has created circuitry under lab conditions that's only 0.05 microns

Making the Quantum Leap

ERIC YANG

THE LONG-TERM future of electronics may lie within the realm of mechanics—quantum mechanics. So-called quantum computers lie somewhere between theory and reality. There are no such machines today, and most experts think it will be decades before one is practical. But they are considered a mathematically provable possibility.

What's a quantum computer? Rather than define information as simple on/off bits processed through transistors, the way current binary computing does, quantum computers use an entirely different—and deeper—computing model based on quantum mechanics, or the behavior of individual atoms and electrons in the physical world. The smallest unit of information in a quantum computer is a quantum bit, or qubit, which is not on or off but exists in multiple states at once, which better lends itself to the parallel processing of computer instructions. And in keeping with the "superposition of states" principle inherent in quantum mechanics, qubits exhibit wavelike tendencies, reinforcing or canceling one another. Programs known as quantum algorithms could take advantage of these waves to reinforce desirable results and cancel undesirable effects, enabling them to more quickly sort through big or complex computations than binary algorithms. Researchers at Bell Labs have already devised one such quantum algorithm for searching through large databases. Computer scientists see other applications in cryptology and mapping.

Not all future quantum computers will harness qubit behaviors in the same way. A team at Los Alamos National Laboratory is working on a prototype quantum computer using an "ion trap" device in which the electrons of suspended calcium ions are acted upon by lasers. Other approaches include "quantum dot" and nuclear magnetic resonance. Whatever their final form and however long it takes, some scientists believe that quantum computers are the inevitable successors to microprocessor-based machines. "Quantum computing is the only thing on the scene that could make a huge difference," says Charles Bennett, a quantum theorist at IBM Research.—*C.O.*

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wide—and they're working on 0.01 microns, which may be as close to zero as we can practically go without shifting to single-electron quantum computers.

But such accomplishments are not a done deal yet. All of these new lithography techniques are experimental, technically arduous, and, for the moment at least, extremely costly.

Lithography is not the only challenge, either. Making tiny transistors even smaller is not as easy as refining the etching tools. As transistors get smaller, so must the insulation layers that separate the gate—where signals come into a transistor—from the source and drain components, where they exit. With inadequate insulation, transistors won't operate accurately, or at all. These insulating layers, known as gate oxides, are perhaps the critical stumbling block to shrinking transistor size and thereby boosting the performance of microprocessors while making them smaller, or at least without making them any larger.

Bell Labs may have an answer for this, too. It recently announced what's billed as the world's smallest practical transistor. By creating an insulating layer that's five times thinner than today's gate oxides—a mere three atoms thick—Bell researchers have produced a transistor that's only 60 nanometers, or 182 atoms, wide. That's four times smaller than the transis-

Supercomputers Unplugged

WILL SUPERCOMPUTERS go the way of the dodo? They might, and ironically enough, it may be the coming superchips of the microprocessor world that make them extinct. At least that's the conclusion of John Hennessey, professor of computer science and dean of Stanford's School of Engineering. "The last bastion of non-microprocessor computing, the vector-based supercomputers, will vanish in the next five to ten years," says Hennessey.

For the past 40 years, supercomputers were marked by highly specialized hardware architectures and customized software to fit unique applications. But recent technical and economic developments have made those machines increasingly less cost-effective. Today's microprocessors are gaining fast on supercomputers' speed and power. Microchips have already made obsolete most minicomputers, once relied on for heavy-duty research, and mainframes, once the workhorses of the corporate world, according to Hennessey. And today, Hennessey says, users get more than twice the processing power per dollar from a desktop workstation as they do from a supercomputer—and it won't be long before they get five times the bang for a buck.

Naturally, as computers based on microprocessors become faster, they get used for more complex applications that formerly required specialized machines. In addition, programmers are becoming increasingly expensive, which means supercomputers can no longer afford to run on totally customized software. "The days when supercomputer users all wrote their own programs are long gone," explains Hennessey.

Microprocessor machines can also be strung together to duplicate or exceed the computing power of supercomputers. An experimental Stanford architecture called distributed shared memory allows an entire network of desktop computers to share the same memory resources and thus act like a single computer. At the same time, "massively parallel" machines are akin to networks of PCs nested in a single box, an approach called cluster architecture. Hennessey believes that if supercomputers survive, they will combine aspects of cluster architecture (now being pursued by IBM, UC Berkeley, and Sandia National Laboratory) and distributed shared memory (being developed by Stanford, MIT, Silicon Graphics, and Hewlett-Packard).—*Arthur Fisher*

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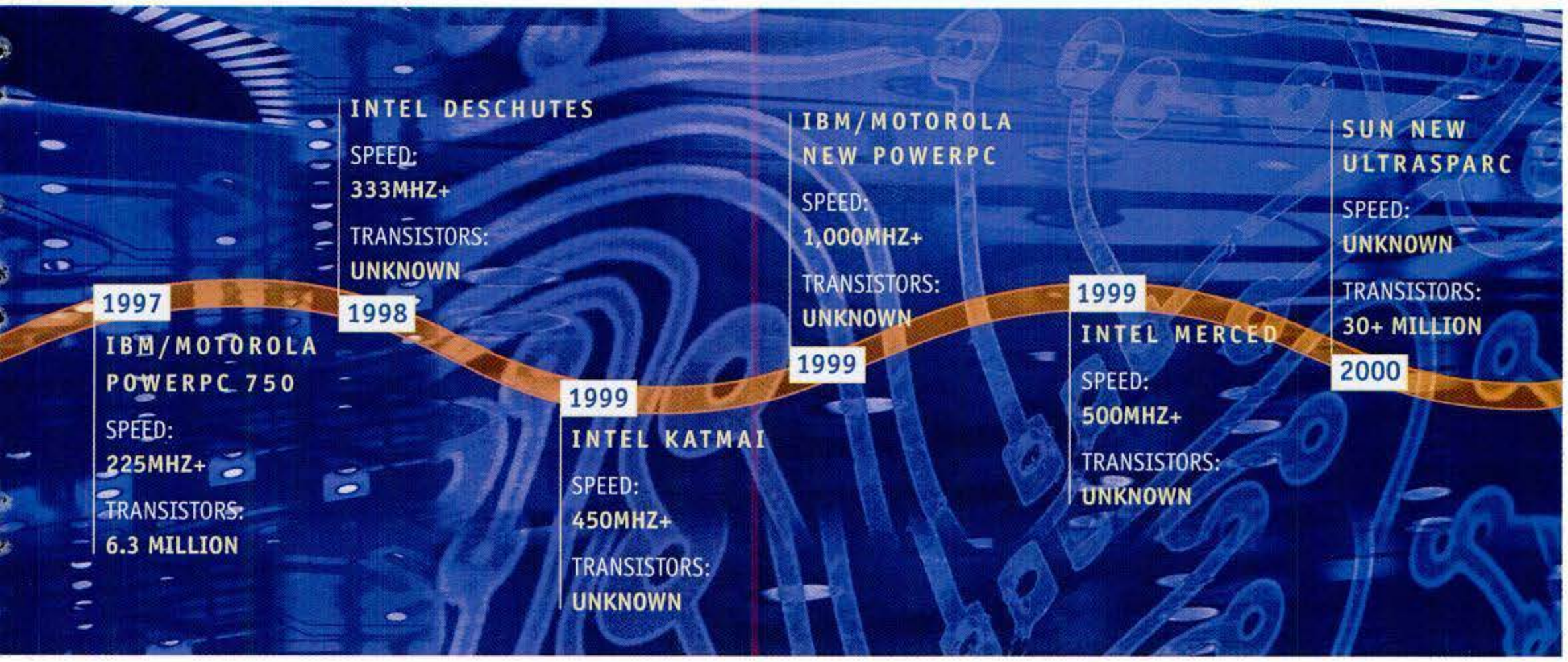

tors in today's chips. Yet, Bell Labs says its tests show that the nanotransistors are five times faster and barely sip electricity, using 60 to 160 times less power than current transistors. Even more remarkable, NEC and other companies are working on even smaller nanotransistors.

Nanotransistors are still experimental, and their use may be eight to 12 years away. But coupled with new lithography techniques, they may provide microprocessor makers with the sort of extended technology roadmap they need. "We are ushering in the age of nanoelectronics," says Mark Pinto, chief technical officer of Lucent's microelectronics group.

There are more immediate improvements to microprocessors coming this year and next. A wave of copper chips may be first. IBM recently announced it has invented a way to use copper instead of aluminum for the circuitry that connects transistors. Copper is a superior electrical conductor, resulting in about 20 percent better performance than a comparable aluminum design, but had been difficult to adapt to silicon chip manufacturing. More important than the short-term performance boost, IBM's breakthrough may permit chips to get smaller even as they host more transistors—possibly as many as 150 to 200 million on a single chip, according to IBM.

The first copper-based microprocessors for PCs and workstations could come later this year or by early 1999, and probably earlier in specialized chips such as 3-D graphics controllers. "Eventually, everybody will be on copper," says Jim Glaze, vice president of technology programs for the SIA.

To go forward faster in the near term, chip makers may have to think parallel, too. Intel is doing just that with its Merced chip, a 64-bit microprocessor that the company is developing with Hewlett-Packard. Merced, due next year, and its successors will use what the companies call "explicitly parallel instruction computing." It's a relatively straightforward concept: Allow the software to tell the microprocessor which instructions can be performed at the same time, or in parallel. Groups of chips are often used in parallel, **especially in supercomputers**. But individual chips usually execute instructions in sequential order, like a cafeteria line. Merced effectively opens up several new counters (Intel won't say how many yet) to serve more customers faster.

The key to this new single-chip parallelism was recognizing that the compiler programs used to translate software instructions into the machine codes a microprocessor can understand were already smart enough to separate sequential and parallel tasks —the chips just weren't taking advantage of it. "The best ideas always seem obvious once you're exposed to them," says John Crawford, director of microprocessor architecture for Intel.

Intel certainly has no corner on the market for good ideas, but it does have a bigger bank account than others. And money may wind up playing as big a role in sustaining—or stepping back from—Moore's Law as any technology discoveries. New chip fabrication plants, or fabs, cost about $2 billion today, and the price tag could reach $10 billion in a few years with all of the new equipment needed to make these superchips. Competition usually makes for better products, and microprocessors are no exception, but it's not clear how many players will be able to afford to play the superchip game. It's also not certain that these new fabs can crank out chips that are cheaper as well as better.

"The key question is not whether you can design and demonstrate new microprocessors, it's whether you can manufacture them," says the SIA's Glaze. "At some point, you can no longer shrink these microprocessors economically."

Then again, when the chips are down, chip makers have been up to the task. "Every few years we find solutions to problems and move on," says Amant Agrawal, vice president for performance microprocessors at Sun Microelectronics, with an optimism born of a quarter-century track record of amazing progress. "We can still do that." ◆

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Urban Rainforest

An African jungle comes to life on New York's west side.

AS THE RISING SUN sets the morning sky aflame, the play of light across the thick vines and verdant trees is almost hypnotic. Dozens of birds, representing a vast array of species, create an outdoor symphony. The forest is ripe with nuts, berries, and bunched fruit. Ahead, where the jungle breaks, elephants trudge toward a marshy, open clearing, or bai.

By Bob Sillery

An African rainforest? Well, sort of. This drama is unfolding on the west side of the island of Manhattan in New York City. Tree by tree, leaf by leaf, vine by vine, a 2,500-square-foot sector of the Central African Republic's Dzanga-Ndoki Rainforest has been transported to, or recreated at, the American Museum of Natural History's new hall of biodiversity. When the hall opens this May, visitors will trek through one of the world's biggest and most complex dioramas, a painstakingly accurate, lifesize reproduction of one of nature's most threatened creations.

To bring the rainforest to New York, a team of nearly two dozen ornithologists, mammalogists, exhibition preparators and designers, and audiovisual technicians—the largest collecting expedition the museum has ever mounted for an exhibit—spent five weeks in the African rainforest collecting soil, plants, and leaves; recording and documenting species; fashioning casts of trees; shooting videotape and still photos; and interviewing indigenous peoples. "This area has been explored very little," says Joel Cracraft, curator of the museum's department of ornithology, who estimates that the museum will eventually tally 150 to 180 species of mammals, more than 300 species of birds, hundreds of butterflies, and hundreds of thousands, if not millions, of organisms. The exhibition may even have yielded a special prize—scientists suspect they have uncovered several new species.

After the team returned to New York, the forest, nurtured by a blend of acumen, craftsmanship, artistry, organization, and technology, took root and blossomed. Computer-modeling programs plotted distances and spacial relationships. Blueprints began to proliferate across the former hall of invertebrates. Artists studied photos and brought what they saw to life. Plaster trees sprouted, to be daubed with brown and green blotches. Taxidermied animals from the museum's vast attic began to populate the jungle.

The light in the forest—one of the exhibit's cleverest re-creations—will seem uncannily real. Long tube lights will have the correct color temperature to produce a natural effect. Optic fibers hidden in vegetation will dapple the lush jungle. A system of hidden monitors and mirrors will bring detail and background activity to the setting.

To give the forest a sense of depth, projected and digitized images will fill up the canvas behind the diorama—the back wall of the exhibit is an enormous videoscreen. Sounds will emanate from hidden speakers, and tentative plans even call for jungle smells. Computer controls will vary the effects so that no two walkthroughs will ever be exactly the same.

The diorama is the centerpiece of the 11,000-square-foot hall. "Habitats of the World," a multiscreen video presentation, will complement the rainforest by examining nine ecosystems. Finally, the 100-foot-long "Spectrum of Life" will surround visitors with more than 700 mounted specimens and models, from microorganisms to giant mammals, encompassing 3.5 billion years of evolution but representing a fraction of Earth's life forms. Flying and swimming creatures will hang from the ceiling like a canopy.

The plants and animals depicted throughout the hall exist naturally in a delicate balance—remove one, and the whole is lessened if not endangered. The exhibit is testimony to the hope that the world's jungles will never exist solely as a carefully preserved artifact. ◆

INFOGRAPHIC BY GORKA SAMPEDRO

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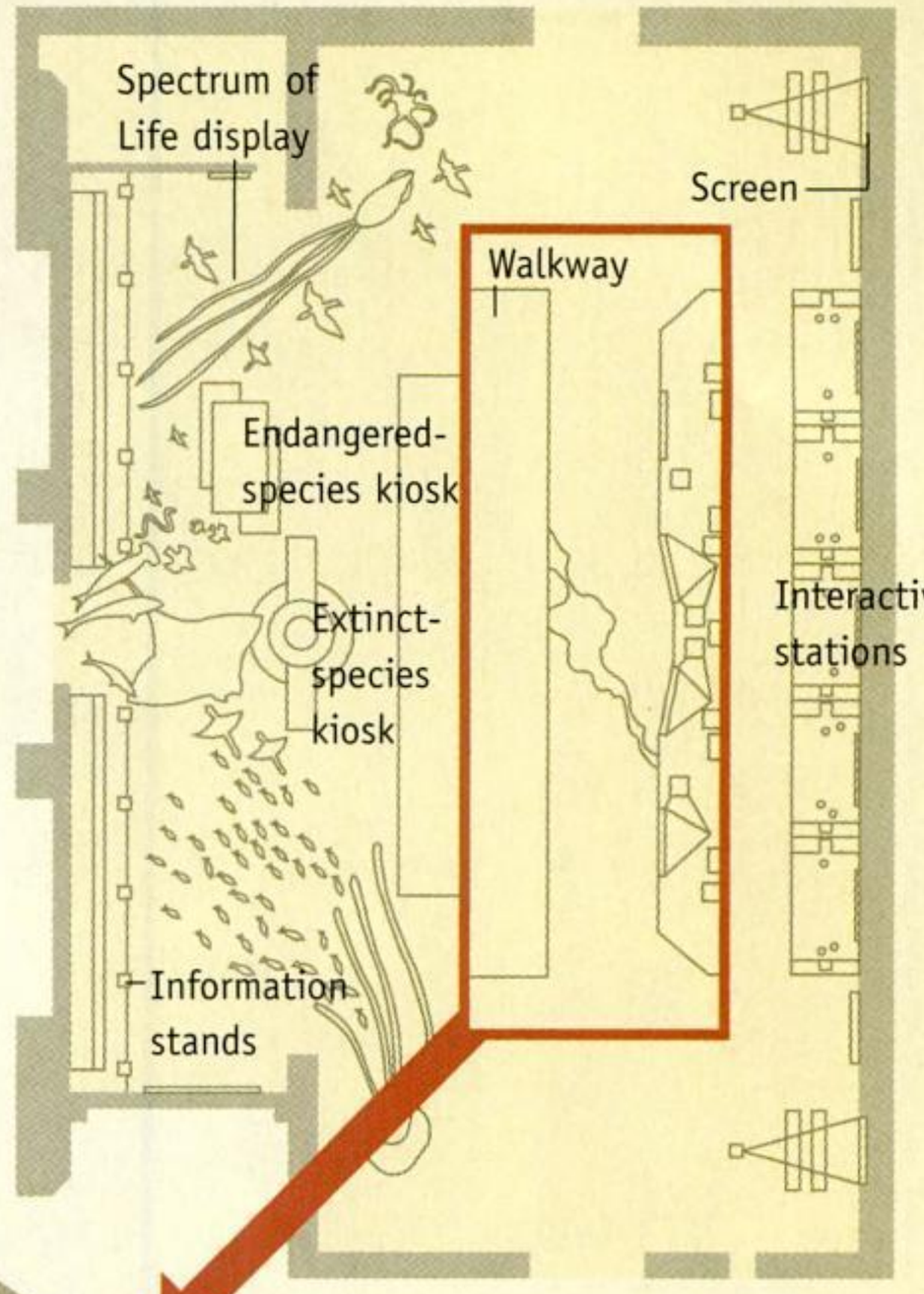
Rainforest Diorama

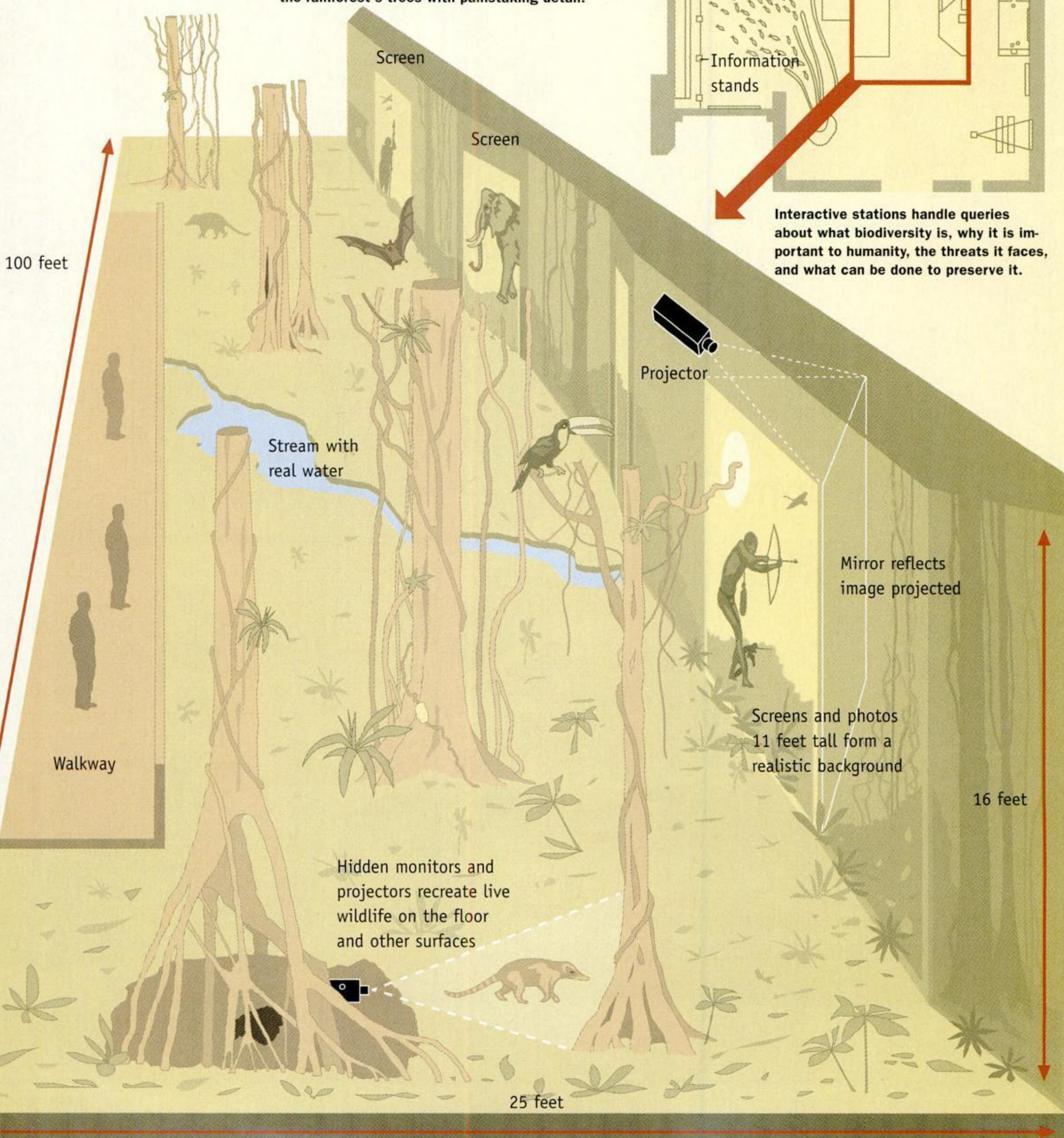
THE DIORAMA depicts the interactions and interdependence of living things in an environment rich in biodiversity. It uses high-resolution imagery, video, and sound to immerse visitors in a setting where animals appear to move and lighting simulates different times of day.

JOHN B. CARNETT

Artisans, working from photos and casts, re-create the rainforest's trees with painstaking detail.



Interactive stations handle queries about what biodiversity is, why it is important to humanity, the threats it faces, and what can be done to preserve it.



Hybrids Get Real

Could your next car be an energy-efficient high-tech hybrid?

PRIUS

DRIVETRAIN: Gas/electric hybrid

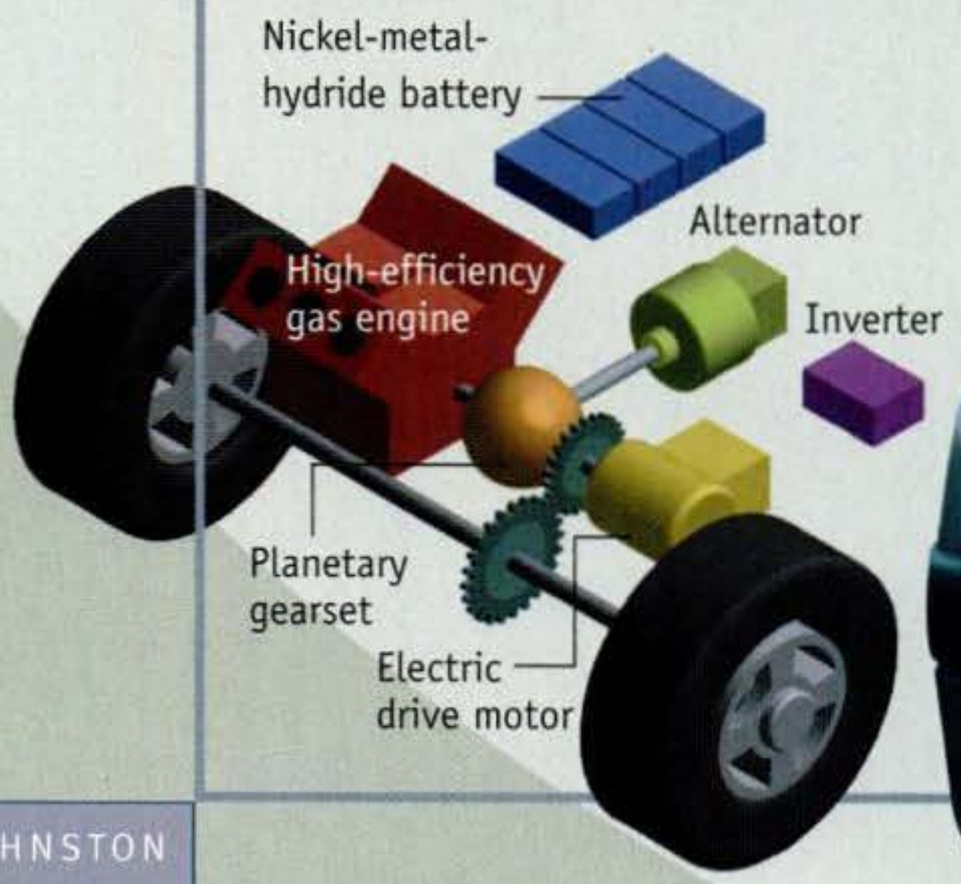
BATTERY: Nickel-metal hydride

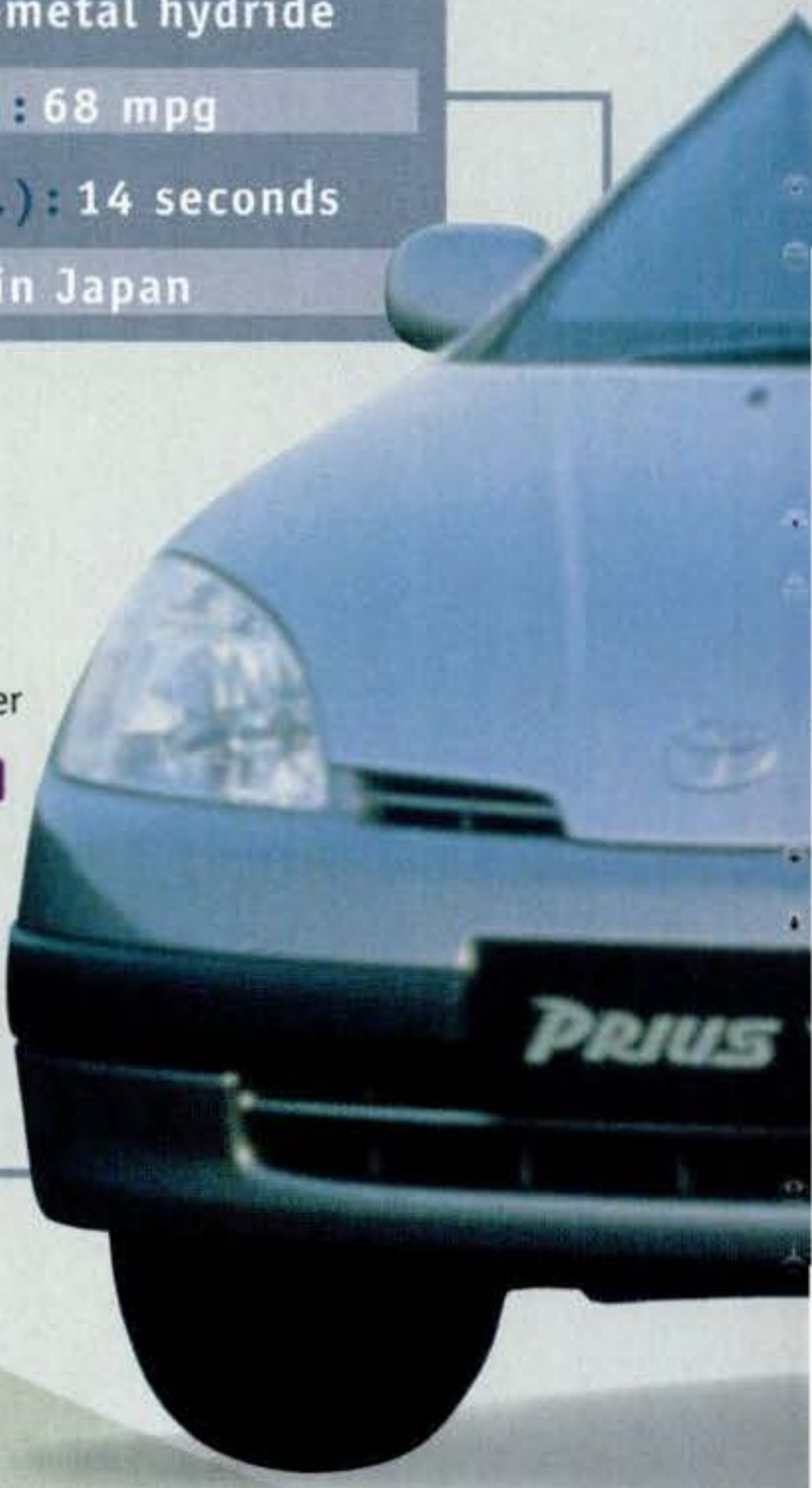
MILEAGE (EST.): 68 mpg

0-60 MPH (EST.): 14 seconds

STATUS: On sale in Japan

TOYOTA





INFOGRAPHICS BY TREVOR JOHNSTON

"YOU HAVE TO be careful coming up behind a bicyclist. They can't hear you; sometimes you can see them jump," says Janet Gray, whose Honda EV Plus is one of the first electric cars driven regularly on U.S. roads.

By Dan McCosh

When Gray and Peter Lucey leased the Honda EV Plus to replace the family's aging Saab 900, they hadn't exactly been looking for an exotic car. But having a Ferrari in the driveway would be commonplace by comparison. Only about 500 electric cars were sold last year in the United States, mainly to government and utility-company fleets—a fraction of the 15 million vehicles sold nationwide.

A quick review of proposals to develop a high-tech alternative to what Ralph Nader calls the "infernal internal combustion engine" reveals no shortage of working prototypes. Ford recently joined with Mercedes and Canada's Ballard Power Equipment Inc. in a $1 billion crash program to develop a viable fuel-cell automobile in the next decade. The U.S. Big Three automakers continue working in a partnership with the federal government to develop an 80-mpg family sedan, and Chrysler, Ford, and General Motors are working on concept cars to meet this goal. European automakers likewise have demonstrated research exercises in high-mileage technology.

Still, it is a big leap to go from research—even building a handful of workable prototypes—to mass-producing, distributing, and servicing an alternative-power automobile for daily use. The list of alternative-engine casualties

NOW ON SALE, TOYOTA'S Prius hybrid-drive car combines a high-efficiency gasoline engine and electric drive. An onboard battery balances the power flow to conserve energy. The Prius claims close to 70 mpg, making it one of the most fuel-efficient cars in the world.

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INTREPID ESX2

CHRYSLER

DRIVETRAIN: Direct-injection diesel/"mild" hybrid

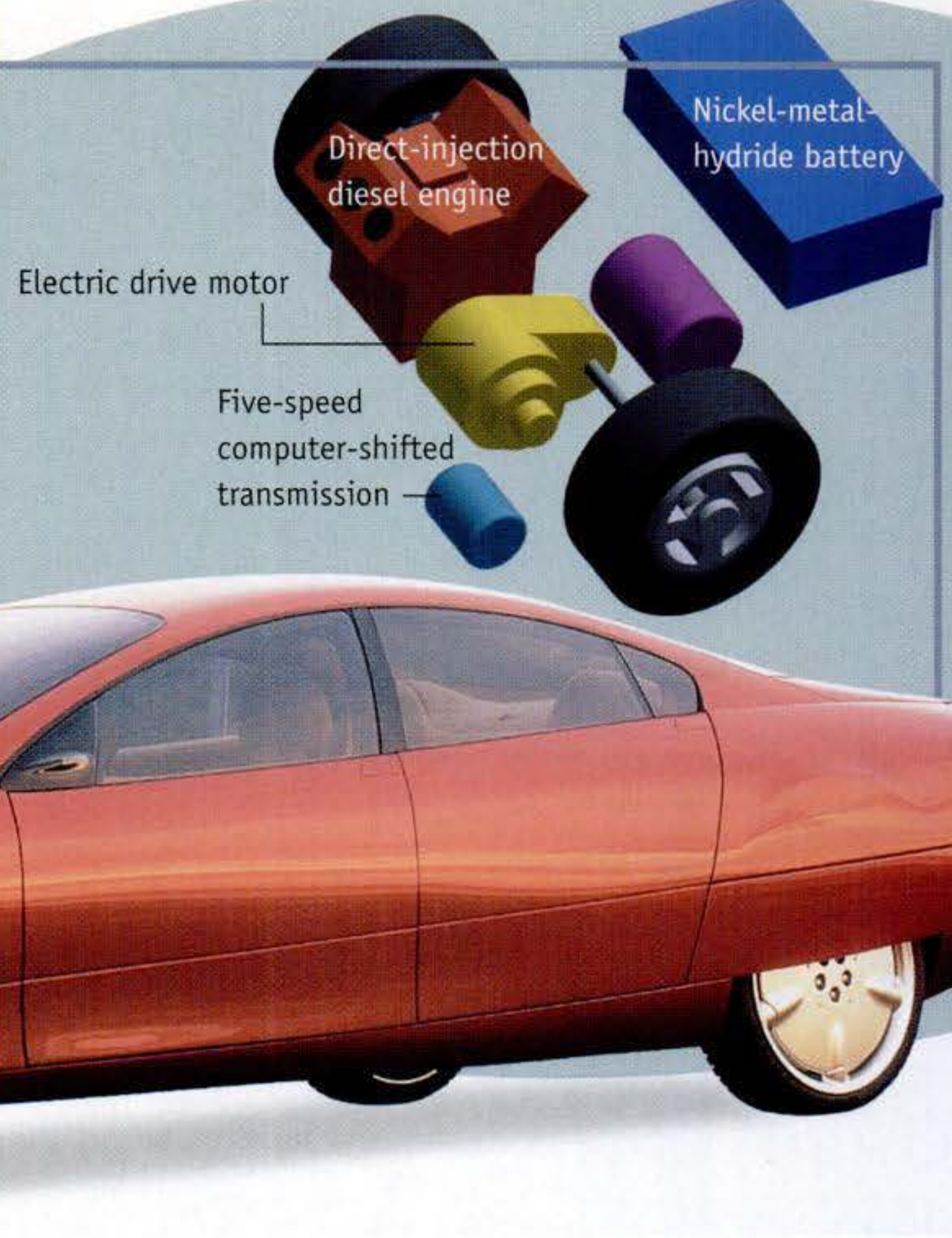
BATTERY: Nickel-metal hydride

MILEAGE (EST.): 75 mpg

0-60 MPH (EST.): 12 seconds

STATUS: Testing begins mid-1998

CHRYSLER uses a small battery and a computer-controlled manual gearbox to combine electric drive with a high-efficiency diesel engine. The body of the experimental hybrid is made of lightweight, injection-molded plastic, further enhancing the efficiency of the car as well as promising lower production costs.



since the 1974 energy crisis reads like a high-tech version of the Vietnam War Memorial. Steam, stirling, stratified charge, gas turbines, PROCO (programmed combustion), the Wankel, and various diesel derivatives all have had their day in the sun. Even the sun has had a shot at it, if you include the ultralight gizmos that have raced across the Australian desert under solar power.

A handful of electric cars from major manufacturers are in production. So far, however, sales of General Motors' EV1 have been so slow that the plant was temporarily shut down last July, and will stay shut until the surplus production has been sold.

Arguably the strongest push to develop new hybrid technologies is coming from Japan, where Toyota recently launched its hybrid Prius sedan. Prius is the first car on sale to the general public—albeit only in Japan—with a hybrid-drive system.

The Prius uses a combination of gasoline and electric drive to produce a claimed 70 mpg in daily use. As production got under way in December, advance orders seemed quite strong.

Despite the lack of interest so far from the motoring public, some are still hopeful that it is only a matter of development time before the hum of electric motors replaces the rap of dual exhausts. Mass production eventually will bring the cost down, goes the theory. And a combination of a growing public concern over car-emission contributions to global warming and old-style smog-producing emissions—coupled with the sheer fascination about new technology—spells doom for the conventional gas-powered piston-engine car, at least sometime early in the next century.

A closer look at the list of problems to be solved before a high-tech automobile becomes commonplace, let alone mainstream, reveals something else: Solutions sometimes spawn new problems. Among these problems are limited supplies of new materials required for the technology, lack of fuel or infrastructure, or even something as mundane as the lack of production plants that can make critical components in sufficient volume. But the chief stumbling block is the sheer cost of high-tech drivetrains.

Typical of how difficult these issues can be is the ongoing search for a high-capacity battery, which is essential to all-electric vehicles and critical to most hybrid designs as well.

Several new batteries have the potential to expand the range of an electric car to 150 to 200 miles with average use. Honda and Toyota already are using nickel-metal-hydride batteries, albeit in limited numbers. Nissan is venturing ahead with a lithium-ion battery, which has an energy-storage capacity about double that of conventional lead-acid batteries. This spring, the first lithium-polymer battery pack, with an even higher energy capacity, is being tested by a joint venture of 3M Corp. and Hydro Quebec. Another contender is a sodium-chloride battery—likewise a powerful candidate.

But demonstrating superior performance potential is a long way from making an affordable battery. A Chrysler study of electric cars concludes that the whole car, sans battery, can be built for about the same price as

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a gasoline-powered equivalent. The cost of the battery thus becomes the incremental price of the new technology. But those increments can be enormous—tripling or even quadrupling the cost of the car.

The demonstration programs for electric cars often mask this issue by subsidizing the cost of the battery—the $100,000 Chrysler charges for its electric minivan more accurately reflects the cost of its battery pack than does the $499-a-month lease for a Honda EV Plus. The $3,000 battery pack now in GM's EV1, for example, lasts about three years, which means it costs roughly double the price of gasoline consumed in an average sedan annually. The nickel-metal-hydride batteries, considered the technology of choice for the next generation of electric car batteries and already in use by Honda and Toyota, now cost nearly $30,000—roughly triple the cost of a small car.

Batteries big enough to power a car also are scarce. Small nickel-metal-hydride batteries are commonplace as the power sources for computers and cellular phones, for instance. But the high current draw required by an electric car demands new technologies. Battery packs big enough to power an electric car are not in full production anywhere. The more exotic batteries, including lithium ion and lithium polymer, are still in the laboratory stage. Nickel-metal-hydride battery packs are mainly being built in small prototype shops. The exception is a prototype assembly line running at Panasonic, capable of turning out about 1,000 battery packs a year—the source of the batteries in the Toyota RAV4 and Honda electric cars.

Could this picture change? GM recently announced it would be offering nickel-metal-hydride batteries in its EV1, and expects a three-stage program to cut the cost of its EV battery to the equivalent cost of gasoline in about five years.

Aside from the batteries, a conversion to electric power, for either pure electric or hybrid vehicles, needs electric drive motors capable of powering the car. A car motor needs to be light and powerful. As with batteries, many designs offer promise but few are available in any substantial numbers. But the main factors inhibiting the use of electric power are the design, cost, and availability of high-amperage power controllers.

Switching the high current loads in an electric car is the enabling technology that makes lightweight AC induction motors feasible. It's also essential in controlling the power flow in hybrid-electric vehicles.

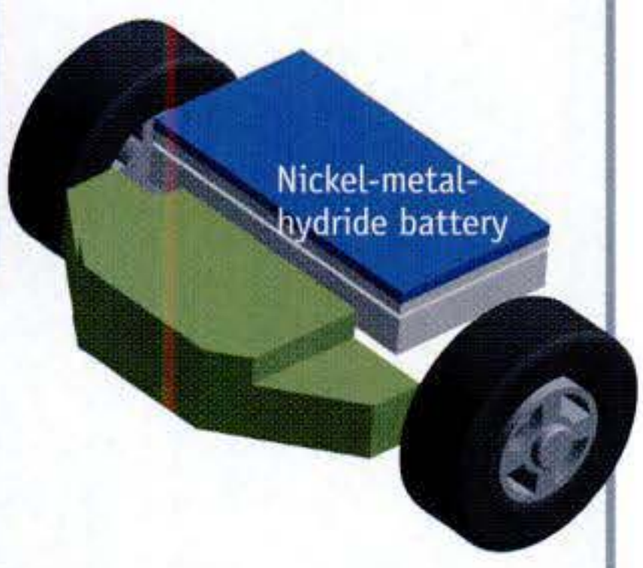
Again as with batteries, successful power controllers tend to be expensive. Unlike batteries, however, solid-state power controllers of various designs are relatively recent inventions—hence the hope is they will drop rapidly in cost, as do many semiconductor-based technologies. Here again, GM claims the solutions are near at hand—and says that a program will reduce the weight and cost of its electric drivetrain to the equivalent of a gas engine within about five years.

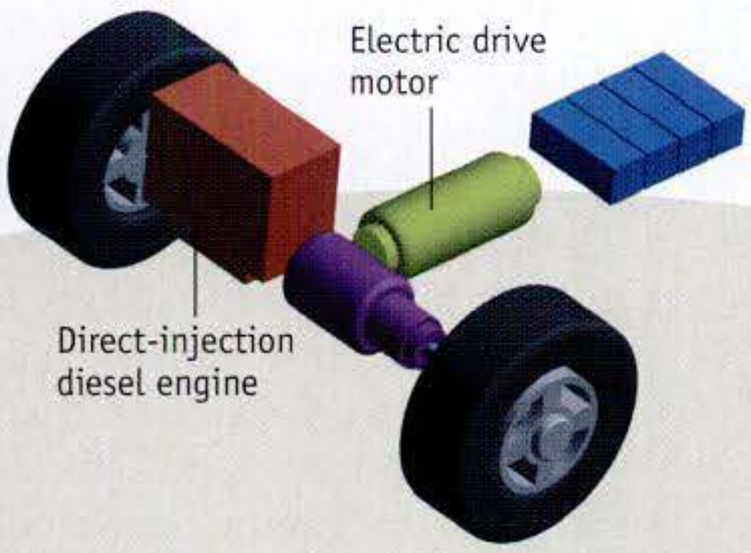
Even the seemingly mundane issue of reducing weight in hybrid vehicles is quixotic. Aluminum and composites, often used to keep weight down, are far more expensive than steel. The irony is that these lightweight materials often end up being offset by the extremely heavy

P2000

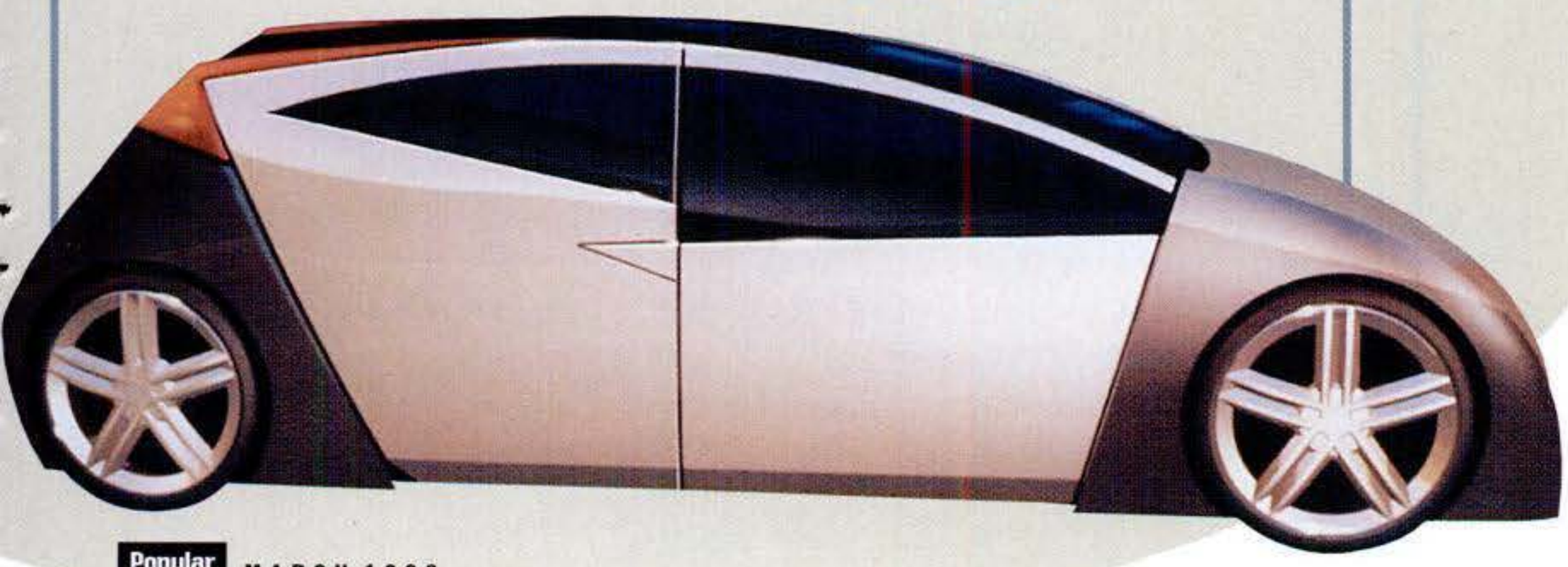
FORD

DRIVETRAIN: Direct-injection diesel/parallel hybrid
BATTERY: Nickel-metal hydride
MILEAGE (EST.): 70 mpg
0-60 MPH (EST.): 12 seconds
STATUS: Testing begins mid-1998





FORD'S P2000 CAR uses an aluminum body to reduce weight, and a new direct-injection diesel for primary power. A parallel hybrid drive further enhances efficiency. To meet existing emission standards, Ford proposes a new kind of clean diesel fuel that still needs to be developed before it is widely available.



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Fuel Cells: Around the Corner?

EFFICIENTLY converting hydrogen to electricity with a fuel cell, leaving harmless water vapor as the only byproduct, has been one of the most promising alternatives to the internal combustion engine—for decades. Recently, it became more than a distant promise when Daimler-Benz announced that it would be producing between 40,000 and 100,000 fuel-cell-powered vehicles by 2004. Meeting that goal would represent a fundamental change in the basic power unit of the automobile.

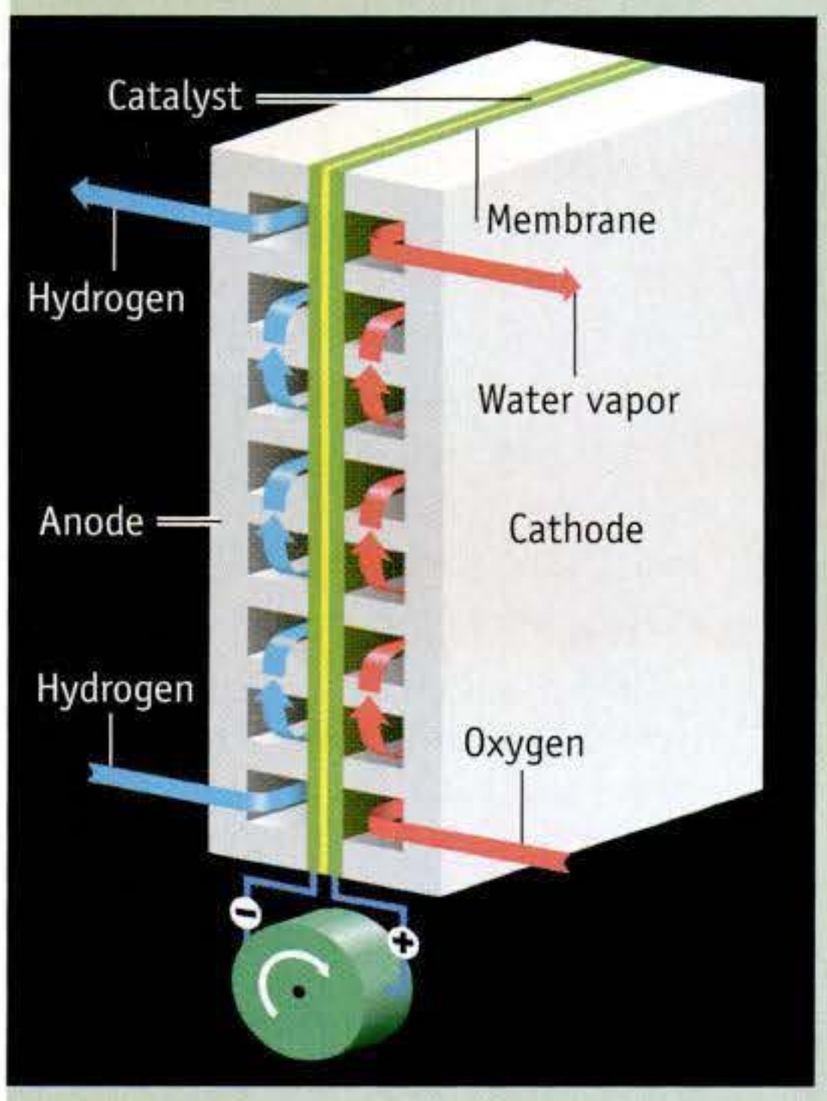
Daimler-Benz's announcement was quickly followed by news of its joint venture with Ballard, prominent among the companies making fuel-cell stacks. Later, Ford Motor Co. joined with Daimler-Benz and Ballard, adding more emphasis to the program. The venture ultimately is aimed at producing powertrains for other automakers as well.

Ballard now says a production-ready fuel cell will be developed within two years. The technology's energy density now is good enough to make a suitcase-size power package that converts the hydrogen to electricity. Hydrogen is difficult to store, however. So a methanol converter that breaks the hydrocarbon fuel into hydrogen and carbon dioxide is part of Daimler-Benz's plan.

Fuel cells operating on gasoline or methanol are less efficient than those fueled by pure hydrogen, since the carbon in those hydrocarbon fuels isn't used to make electricity. Even so, a liquid-fueled cell is expected to get the equivalent of an impressive 80 mpg.

General Motors now says it is working independently to produce a fuel-cell-powered vehicle to be "production ready" in the same time frame.

The rapid emergence of viable fuel-cell technology is tempered by the same problem slowing other alternative-drive systems—cost. The latest estimates indicate that a system with today's technology would cost about 10 times the price of a conventional drivetrain. Ballard expects that changes in materials, combined with high-volume production methods to produce the fuel-cell membranes, will cut the cost within the anticipated time frame.—*D.M.*



A fuel cell converts hydrogen to electricity by combining hydrogen protons with atmospheric oxygen, building a potential across the fuel cell's two sides.

drivetrain components—primarily the batteries, but also some types of electric motors used in these hybrids.

GM's EV1, for example, is at 1,900 pounds one of the lightest production cars ever put on the road. That is, until you add the 1,100 pounds of batteries it carries. In the hunt for extreme fuel efficiency, weight is the enemy. And a hybrid drive carries considerable extra mass compared with a light gasoline engine. The relatively low mass of today's conventionally powered car, achieved mainly with low-cost steel, is one reason why it is difficult to develop a successful alternative.

In the face of these obstacles, the pioneering efforts of GM in launching the EV1 all-electric car and the follow-up efforts of other major carmakers are laudable, but the products available to consumers remain high priced and short of range. But the sudden emergence of the Toyota Prius hybrid-drive car in Toyota's Japanese dealerships is abruptly changing the picture.

At an equivalent price in U.S. dollars of about $18,000—$2,000 to $3,000 more than the same car with a gas engine—Toyota is charging a premium less than that of a typical leather-seat package for a car with an estimated 70 mpg in average use. Toyota executives admit that the retail price does not reflect the actual cost of the car—confirming to some extent that the Prius is still too expensive to compete with conventional drivetrains. But Toyota also insists the vehicle will be profitable if sales hit about 90,000 cars a year—a normal production volume for subcompacts, and well within the capability of the production plant making the car. The Prius thus comes closest to the goal of a reasonably practical alternative-drive car.

It's the interaction of the high-efficiency, constant-speed engine and electric motor that provides the remarkable claimed efficiency of the Prius. The two interact through a planetary gearbox. Sometimes the electric is providing the primary motivating force, other times the two act in unison. The efficiency is gained in several ways—the constant-speed engine itself is claimed to be 25 to 30 percent more fuel efficient than conventional engines, due to its high expansion ratio and lean combustion. The electric drive also allows the vehicle to reclaim energy through regenerative braking.

A closer look at the Prius hybrid also reveals that at least some problems inherent in hybrid-drive systems have been solved. Eliminating an automatic transmission saves both weight and cost, for example. By coupling the electric and piston drive motors though a simple planetary drive, the

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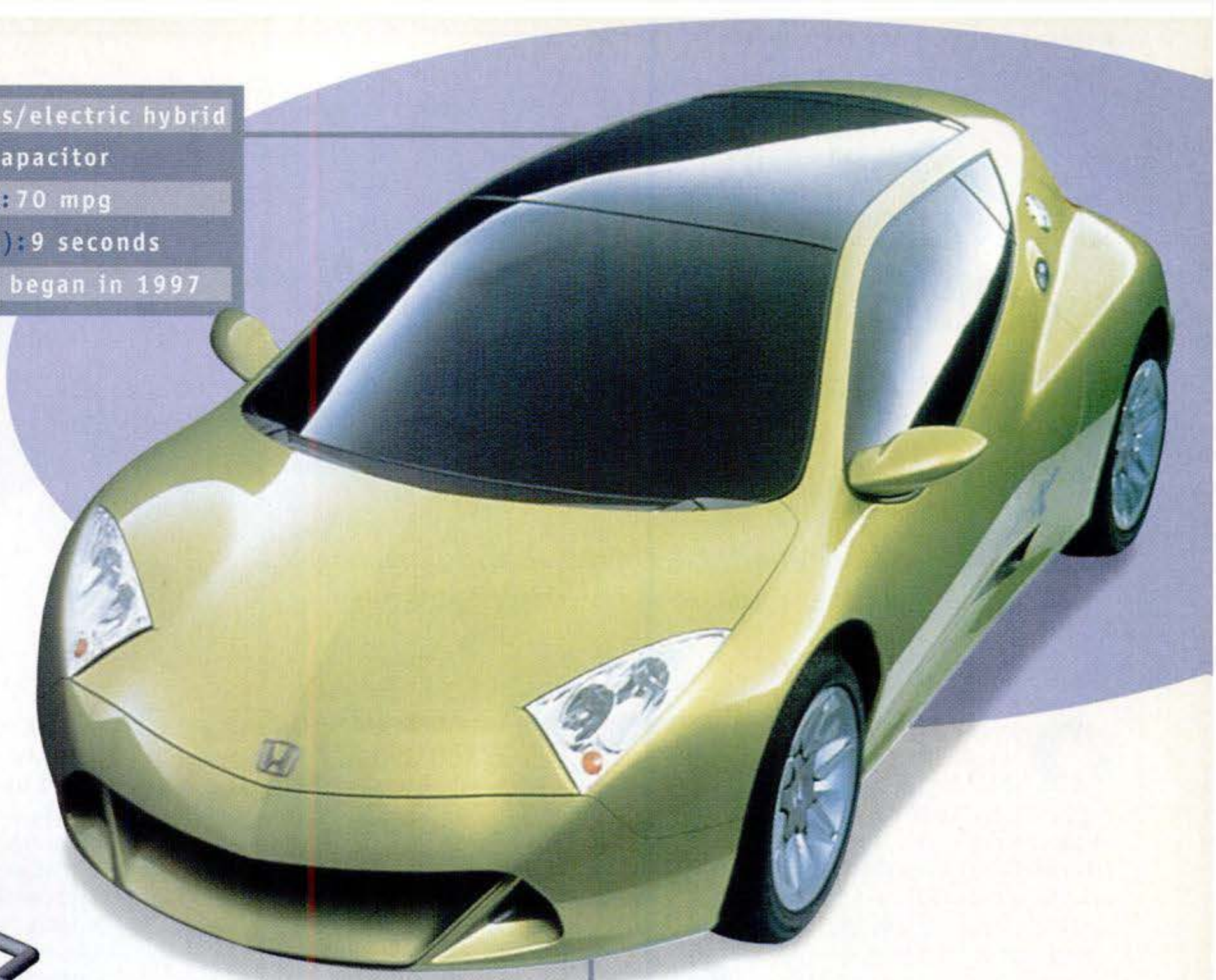
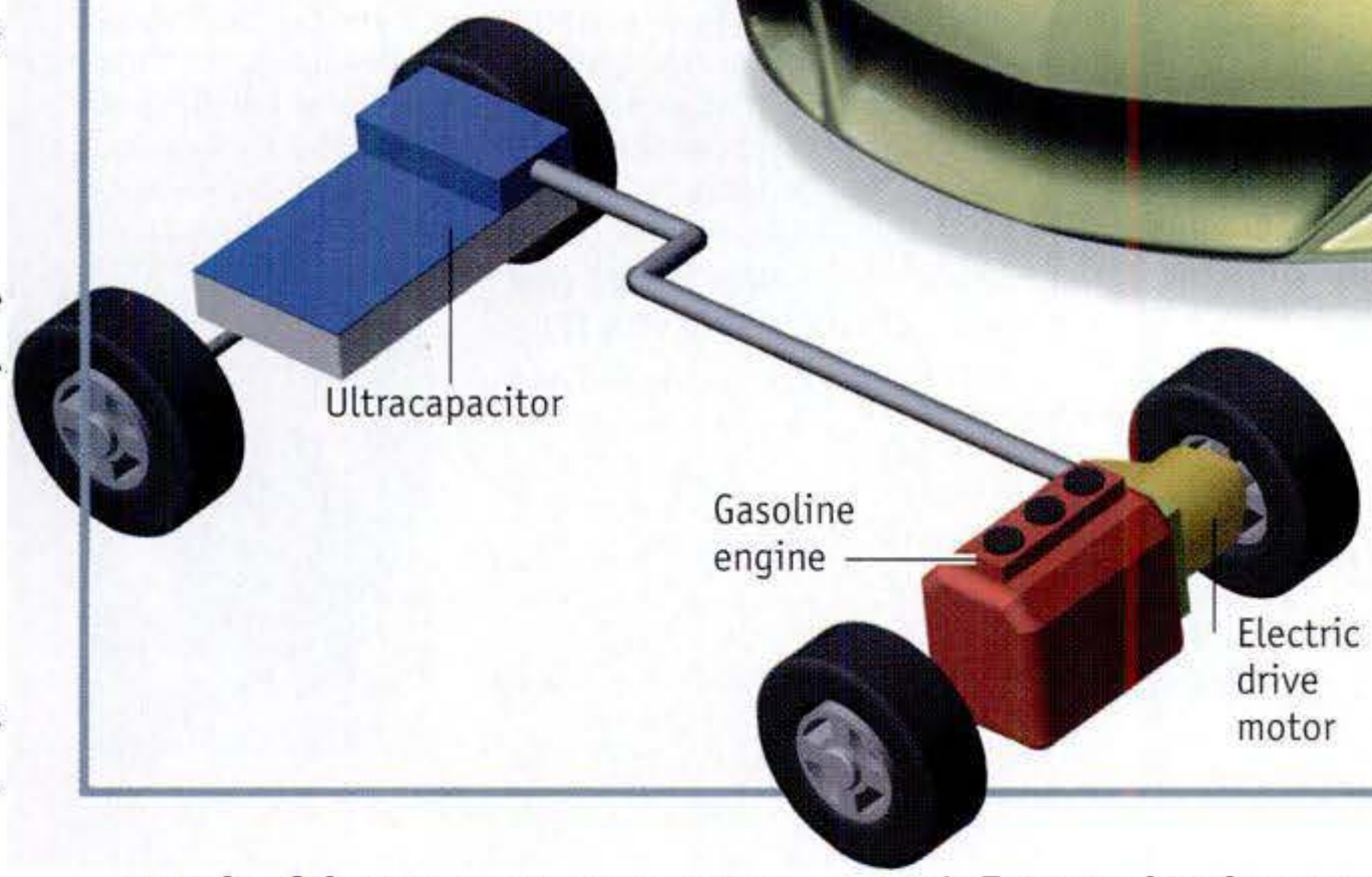
J-VX

HONDA

DRIVETRAIN: Gas/electric hybrid
BATTERY: Ultracapacitor
MILEAGE (EST.): 70 mpg
0-60 MPH (EST.): 9 seconds
STATUS: Testing began in 1997

HONDA'S APPROACH to hybrid drive combines a gasoline engine with an ultracapacitor to store and balance the energy flow. The electric storage system handles high power loads of short duration. The result is a 70-mpg hybrid drive with potentially quick acceleration.





speeds of the two can interact seamlessly; the power of each is controlled by varying power and charging current through a high-amperage controller.

The battery is composed of a series of spiral-wound nickel-metal-hydride cells, adapted from commercially produced power packs.

Outside researchers who have studied the Toyota approach note that the relatively high cost of its electric motor, along with the ancillary battery, could add considerable extra cost. But estimates of the exact amount range from $2,000 to more than $10,000—and Toyota is not discussing the matter. At the low end of this price range, a practical alternative car is just around the corner; but at the high end, it is still years away.

Remarkable as it is, however, Toyota's Prius is already getting caught in the basic scenario that ultimately discouraged research in high-mileage cars in the 1970s: The constant refinement of the internal combustion engine makes it a moving target for technical challengers.

Today, the promise of high-mileage piston engines is coming from direct-injection (DI) gasoline engines and lightweight diesels, some promising extremely low emissions. DI diesel and gas engines promise fuel economy improvements in the 25- to 45-percent range. Mitsubishi expects to use all DI gas engines within two years. So far, the introduction of this technology has been inhibited in the United States by the high sulfur content of U.S. gasoline, which cuts the life of lean-burn catalytic systems.

Lightweight diesels likewise are being introduced rapidly in Europe, and several small cars are claiming mileage in the 60-mpg range. Stringent U.S. emission standards for particulate and oxides of nitrogen, or NO_x—the diesels' weakness—have inhibited development of diesels here.

Regardless, an all-aluminum direct-injection diesel under development at Ford is the basic powerplant for the all-aluminum prototype hybrid-drive concept car recently unveiled at the North American International Auto Show in Detroit. That engine burns an exotic, natural-gas-derived fuel to beat the particulate problem. A recently announced agreement between GM and major oil companies promises to look at the development of alternative fuels.

Alternative-drive concepts by Ford, Chrysler, GM, and Honda also were unveiled at the Detroit show. As a technological tour de force, the show underscored the reality of alternative drive today. The ultralight, ultraefficient concept cars gleamed on the stands, but are still at least several years from the showrooms.

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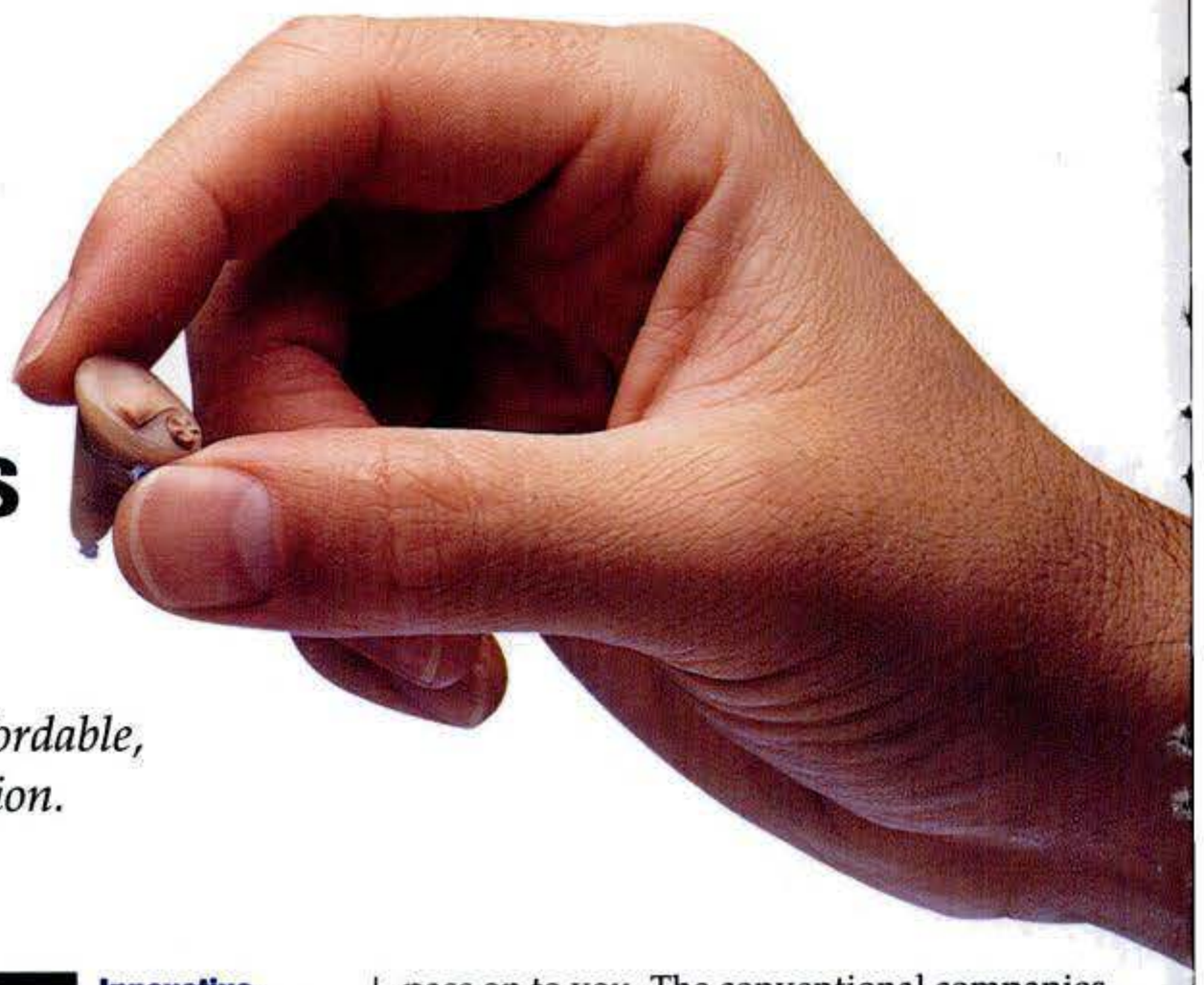
TECHNOLOGY UPDATE

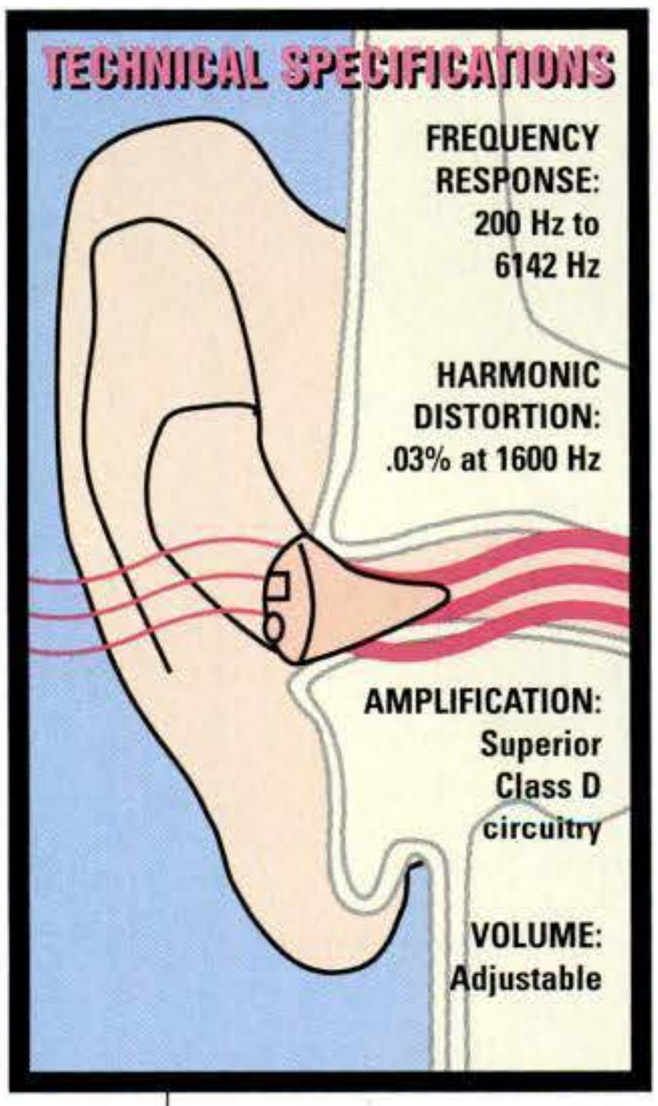
One scientist's vision revolutionizes the hearing industry, benefiting millions of people...

Crystal Ear® uses sophisticated electronics to provide affordable, cosmetically-pleasing and easy-to-use hearing amplification.



One day a friend asked my wife Jill if I had a hearing aid. "He certainly does," replied Jill, "Me!" After hearing about a remarkable new product, Jill finally got up the nerve to ask me if I'd ever thought about getting a hearing aid. "No way," I said. "It would make me look 20 years older and cost a fortune." "No, no," she replied. "This is entirely different. It's not a hearing aid...it's Crystal Ear!"

No one will know. Jill was right. Crystal Ear *is* different—not the bulky, old-styled body-worn or over-the-ear aid, but an advanced personal sound system so small it's like contacts for your ears. And Crystal Ear is super-sensitive and powerful, too. You will hear sounds your ears have been missing for years. Crystal Ear will make speech louder, and the sound is pure and natural.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You'll feel years younger! Wear Crystal Ear indoors, outdoors, at home and at work. Crystal Ear arrives ready to use, complete with batteries, two different fitting sleeves, a cleaning brush and even a carrying case. Crystal Ear is a breakthrough advance in the hearing device field. It is made in the USA, using state-of-the-art micro-manufacturing techniques that cut costs dramatically—savings that we can pass on to you. The conventional companies, domestic and foreign, don't like that!

Don't be fooled by high prices. No hearing device, no matter how expensive, can eliminate background noise, despite claims by the manufacturers. Crystal Ear does not promise miracles—just an affordable, sound solution to many common hearing problems.

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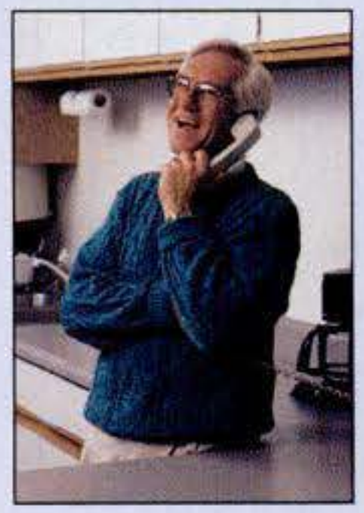

"My father spent over $5000 on another brand. I showed him my Crystal Ear, he tried it, and he decided it worked better than his brand, even though it was a small fraction of the cost!"

—A satisfied Crystal Ear user

"Over 32 million Americans experience some loss of hearing. Though most cases go untreated, over 90 percent of these people would be disappointed to learn from their doctor that there is no medical or surgical cure. There is, however, an effective treatment: electronic amplification."

—Dr. Dale Massad, MD

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FAQ

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ASK POPULAR SCIENCE

How do flowering plants know when to bloom?

John Ramos Bell
via e-mail

LIKE OBEDIENT children, flowering plants do as they're told. But rather than receiving a single instruction that triggers blooming—say, in the form of a change in temperature—plants monitor information or "instructions" from a variety of sources to help them determine when it's time to bloom. "Since plants, unlike animals, are stuck in one location, they need to carefully sense and respond to different environments and conditions," according to Steve Jacobsen, who is a research fellow at the California Institute of Technology. These instructions involve the amount of food and water available, light, and temperature, as well as the age of the plant.

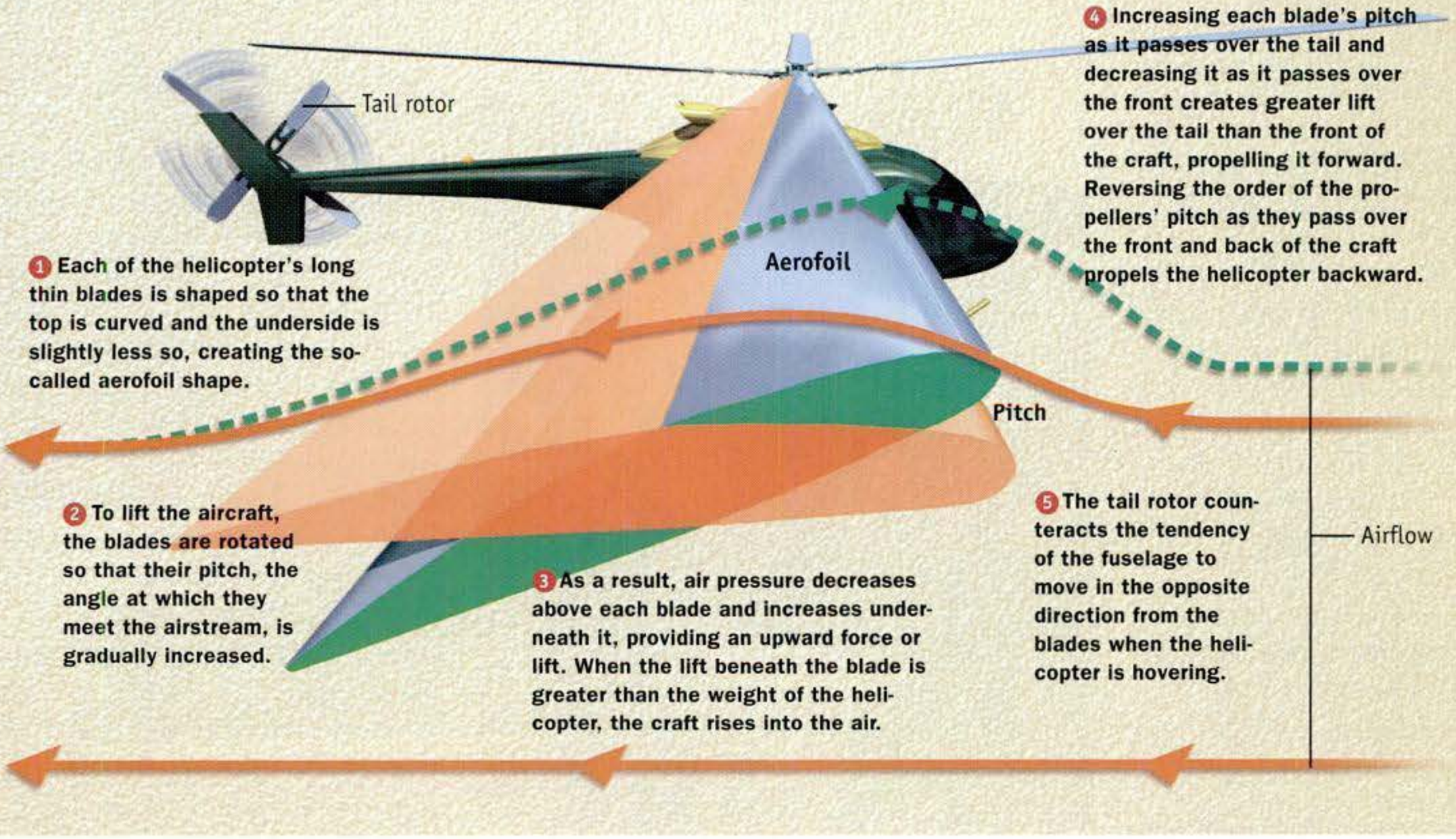
Food and water regulate flowering time in many plants. For example, plants with limited access to nutrients often bloom earlier than those that are well fed. The lack of nutrients actually forces early blooming, as the plant tries to reproduce before it dies.

Special light sensors also influence flowering. These photoreceptors, or light-sensitive proteins, are independent from the green chlorophyll that absorbs light to make energy in photosynthesis. In fact, these photoreceptors tell seedlings that they've broken above the soil line and should begin to photosynthesize.

HOW IT WORKS

Helicopter Flight

THE IDEA OF AN AIRCRAFT lifted and propelled by overhead rotors has existed since medieval times, but it wasn't until 1940 that Russian-born Igor Sikorsky flew the first helicopter. Initially used to ferry soldiers and supplies during wars, helicopters brought new maneuverability to aviation. Here's how they work.—*Gunjan Sinha*



1 Each of the helicopter's long thin blades is shaped so that the top is curved and the underside is slightly less so, creating the so-called aerofoil shape.

2 To lift the aircraft, the blades are rotated so that their pitch, the angle at which they meet the airstream, is gradually increased.

3 As a result, air pressure decreases above each blade and increases underneath it, providing an upward force or lift. When the lift beneath the blade is greater than the weight of the helicopter, the craft rises into the air.

4 Increasing each blade's pitch as it passes over the tail and decreasing it as it passes over the front creates greater lift over the tail than the front of the craft, propelling it forward. Reversing the order of the propellers' pitch as they pass over the front and back of the craft propels the helicopter backward.

5 The tail rotor counteracts the tendency of the fuselage to move in the opposite direction from the blades when the helicopter is hovering.

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THE FACTS

Sky Scope

WITH ITS SPECTACULAR view some 380 miles above Earth's hazy atmosphere, the Hubble Space Telescope produces an impressive string of images and discoveries that scientists are using to help understand the evolution of our universe. (For more on the telescope, see "What's Next for Hubble," page 56.)
—Compiled by Gunjan Sinha

In development for more than 23 years, the telescope was launched in April 1990. Its originally planned 15-year life was recently extended to at least 20 years, until the year 2010.

The 24,500-pound (11,110-kilogram), 43.5-foot (15.9-meter) telescope is about the size of a Greyhound bus.

Intended from the outset to be serviced in space, the Hubble was designed with modular components that can be replaced. The telescope is revamped during each servicing with the instruments that use the latest technology.

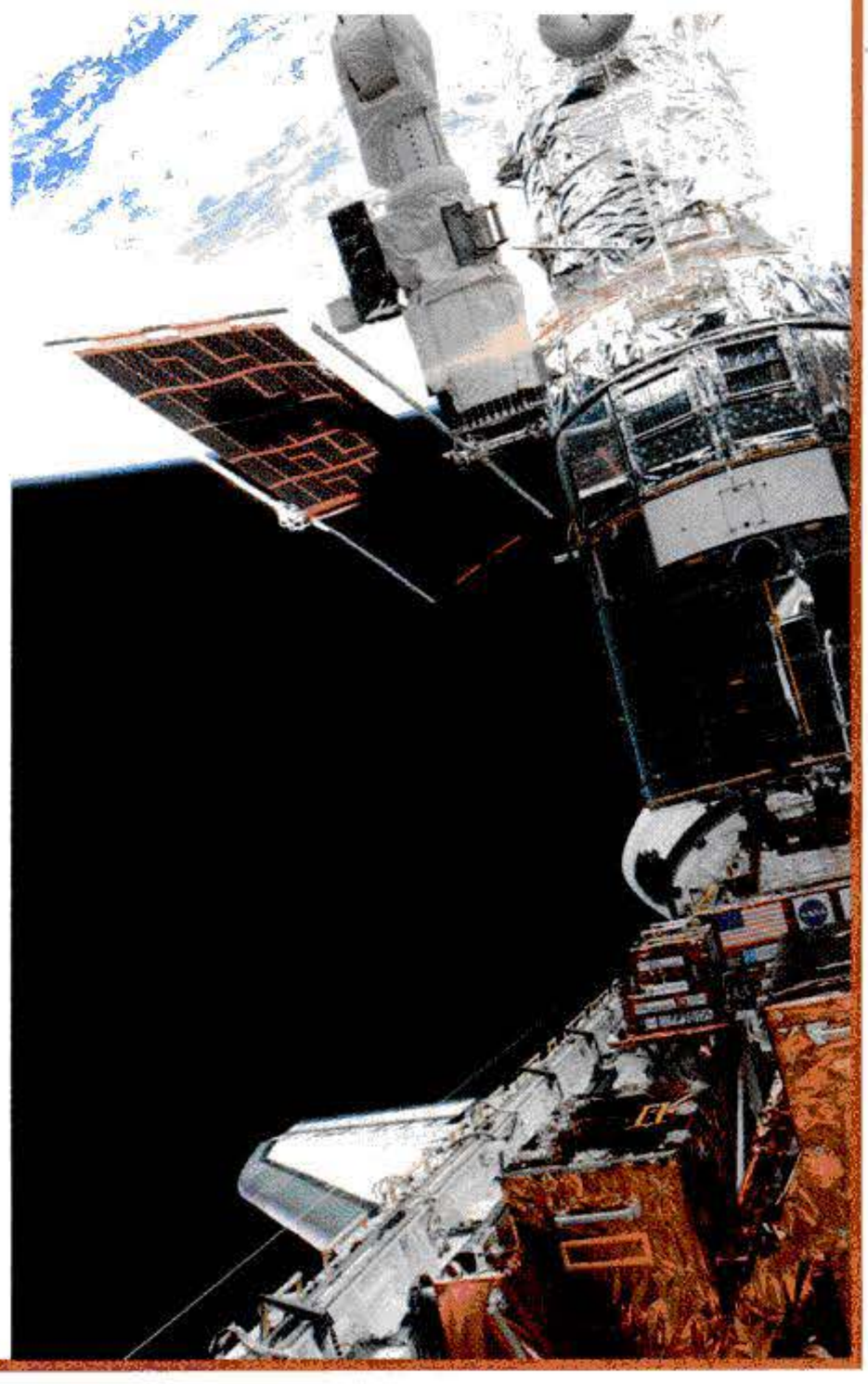
The Hubble has been visited twice for servicing by spacewalking astronauts. A December 1993 servicing mission lasted 11 days, and astronauts made a record-breaking five space walks. During the 10-day mission in February 1997, astronauts also made five space walks. The last two missions are scheduled for 1999 and 2002.

Each orbit around Earth takes 97 minutes. Between observations with its science instruments, the telescope spends much of its time performing "housekeeping" activities, which include turning to face a new target, receiving commands from the control center, and sending data back to Earth.

Images and data collected by the telescope travel 90,000 miles over satellite and ground links before they reach the Space Telescope Science Institute in Baltimore.

The Hubble Deep Field image, a survey made in late 1995, contains the most-distant objects observed to date. It shows almost 3,000 galaxies more than 10 billion light-years away (one light-year is about 10 trillion kilometers, or 6 trillion miles).

The Hubble whirls around Earth at a speed of 5 miles per second. If cars moved that fast, a coast-to-coast trip across the continental United States would take less than 10 minutes.



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Photoreceptors have several classes. Proteins that are known as phytochromes are the major sensor for avoiding shade, measuring day length, and sensing the proximity of other plants, as well as knowing when to flower. There are at least five related phytochromes, says Jacobsen, and researchers are only now beginning to understand the different roles they play in these various processes.

As for temperature, we know from experience that plants won't bloom until the air and soil are warm enough to do so. Unfortunately, nothing is currently known about how plants sense temperature. But temperature is sometimes important to blooming in a way that isn't obvious. Some plants, for example, must go through a cold spell, called vernalization, before they'll flower.

Finally, the age of the plant determines when it flowers. Plants only flower when they're mature, but how plants measure time is another mystery facing researchers.

How are the fat and calories measured that are listed on food labels?

Brandon Knapp
via e-mail

FOOD-TESTING laboratories measure fat content by mixing foods with chemicals that separate out the fat. The exact chemicals and procedures a lab uses depend on the way the fat is complexed, or bonded chemically, within the food.

Take measuring the fat content in a piece of meat, for example. Since the fat either surrounds the meat or sits in pockets within the muscle fibers, the fat content is easily measured. Labs first wash the meat with a solvent, like ether, which dissolves the fat. They then evaporate the ether from the mixture and weigh the remaining fat.

A more complex food—say, a pepperoni pizza—has fat blended into not only the meat, but into the

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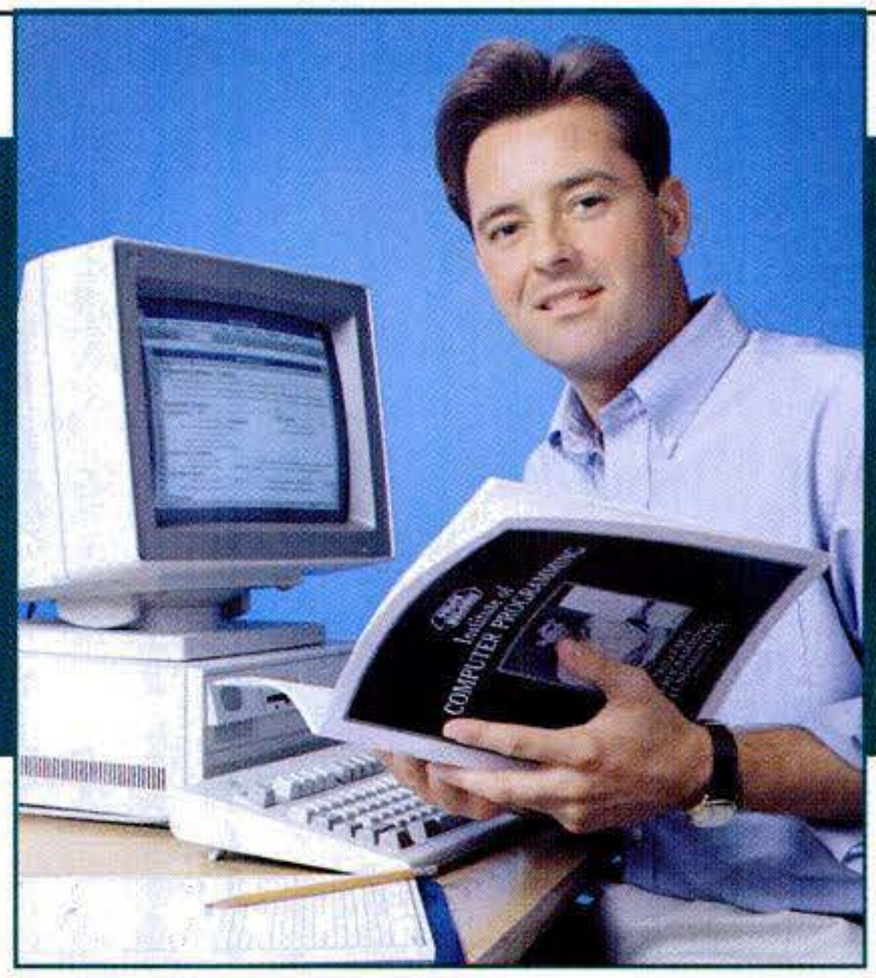

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cheese, the crust, and so on. What's more, these fats are more tightly bonded to proteins and carbohydrates, and therefore must go through several chemical treatments to isolate the total fat content.

To determine the number of calories in a specific food, labs not only measure fat, but also proteins, minerals, moisture, and carbohydrates. Proteins are extracted and measured in much the same way as fat, but using a different chemical process. To measure the moisture, the food is weighed, then dried in an oven before being weighed again. The difference in weight is equal to the moisture content. Finally, to measure the mineral content, the food is burned—literally, it's set on fire—and the remaining ash, or minerals, are weighed.

Adding the weights of the components and then subtracting that number from 100 (as in 100 percent of the ingredients) yields the carbohydrate weight. To determine how many calories are in a specific food, food labs use this simple conversion: 1 gram of carbohydrate is equal to 4 calories; 1 gram of protein is equal to 4 calories; and 1 gram of fat is equal to 9 calories. Water and minerals contain no calories.

For the record, a calorie is the amount of energy it takes to raise the temperature of 1,000 grams (a kilogram) of water by 1°C. Much more loosely, the amount of energy we get from our food by metabolism (the way we "burn" food) is the same as if we had burned it in a fire. ◆

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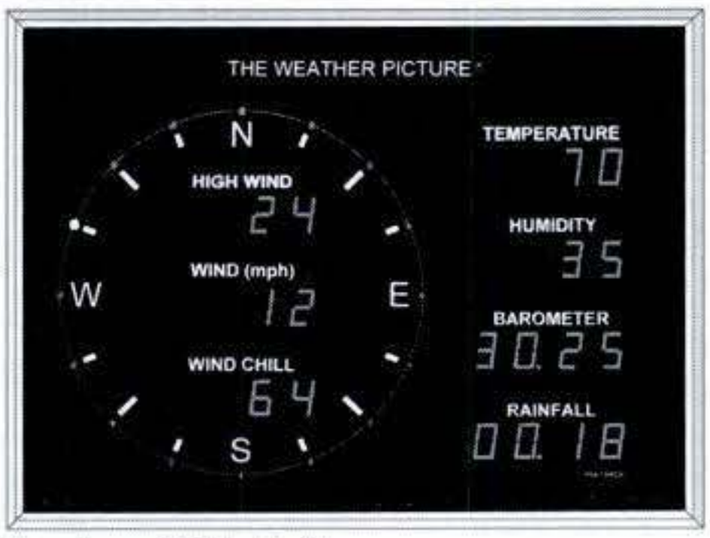

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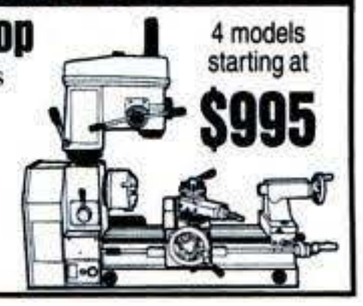

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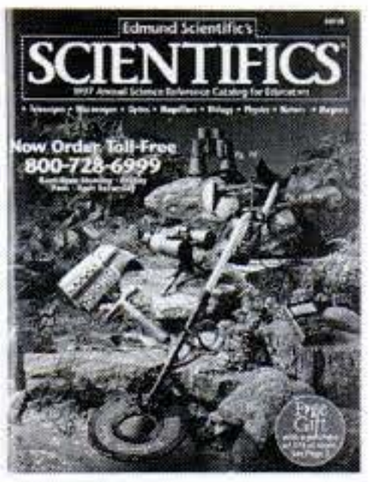

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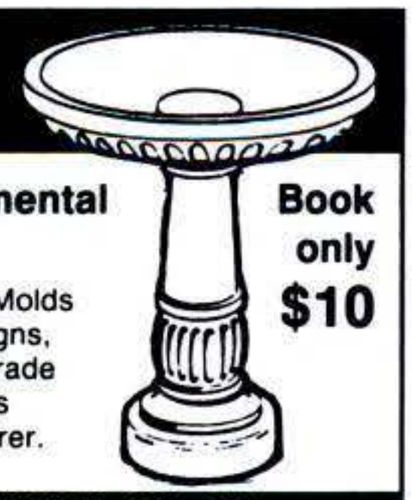

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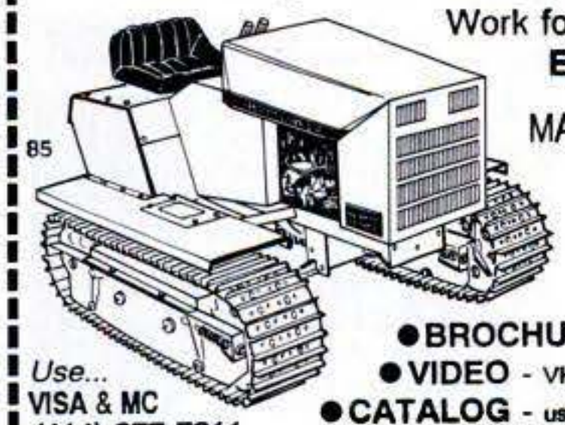

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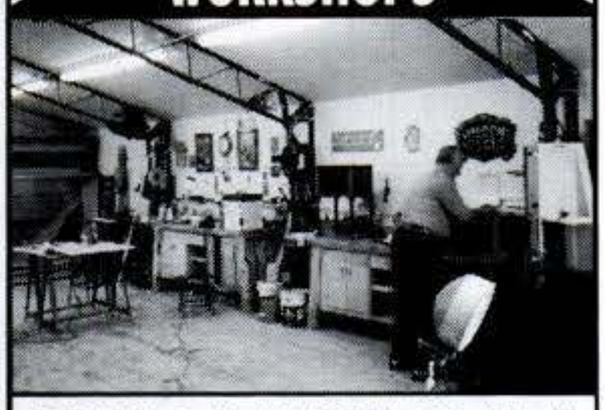

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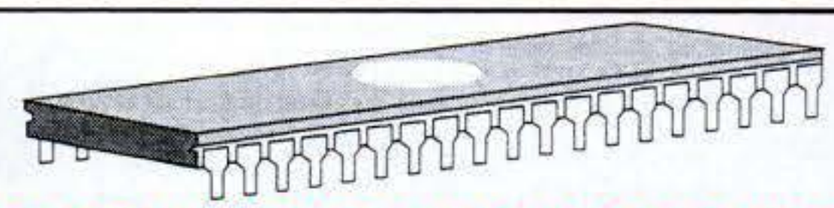

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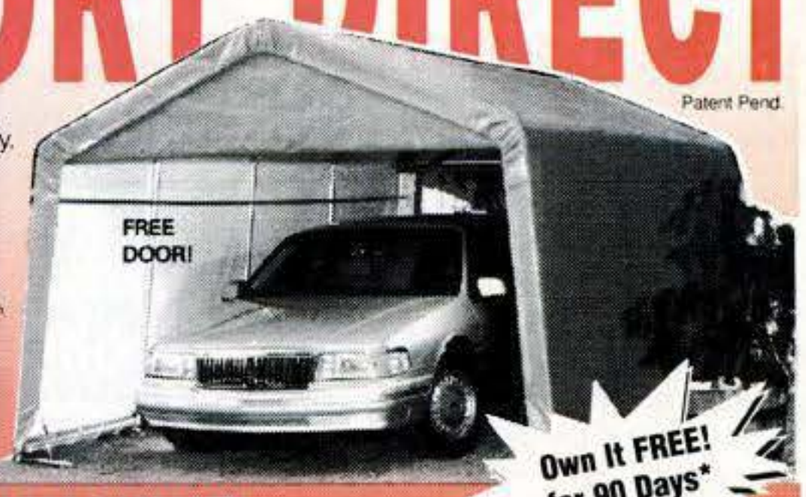

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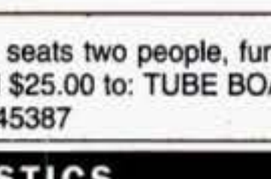

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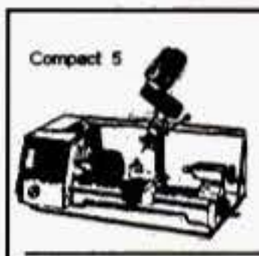

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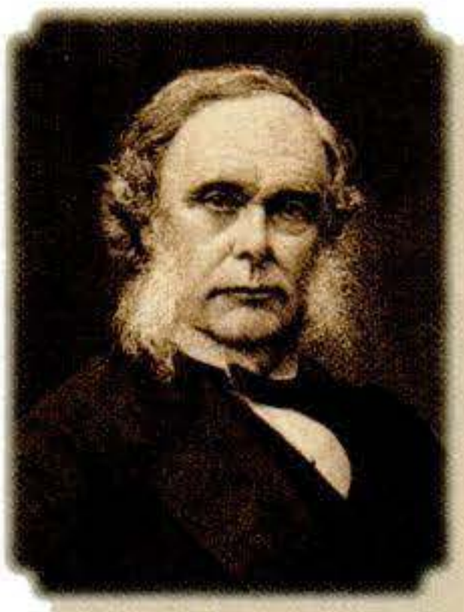


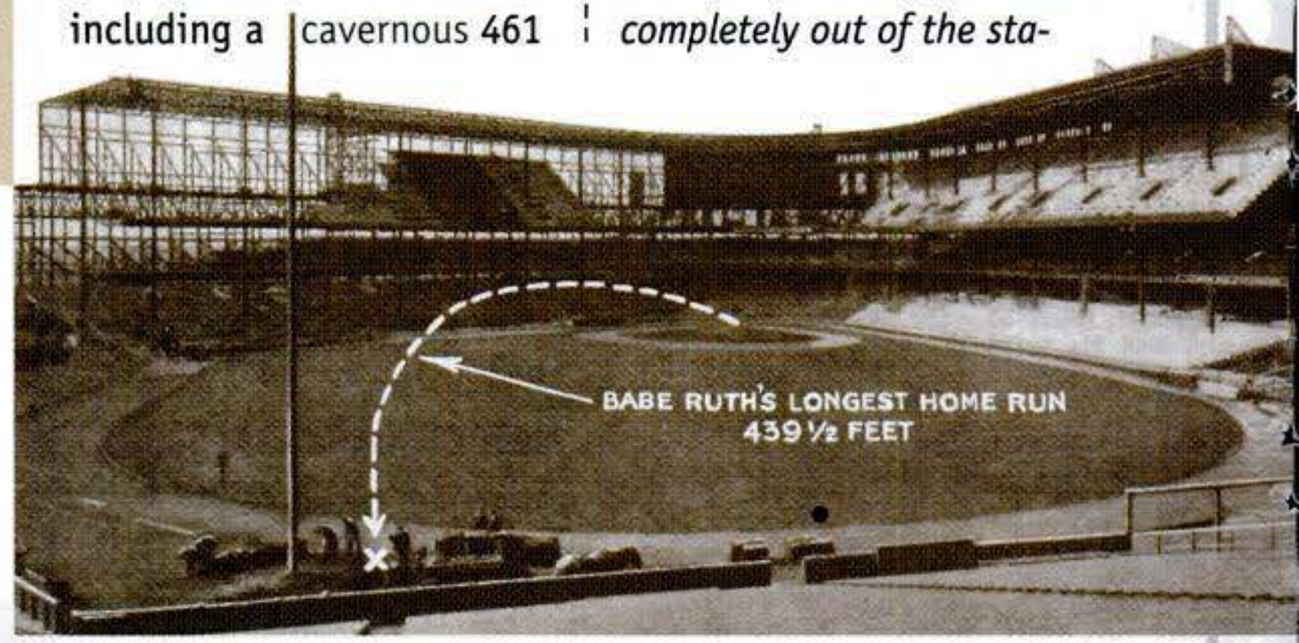
An Extraordinary Surgeon

100 YEARS AGO OUR EDITORS celebrated the achievements of Joseph Lister in the introduction of antiseptic and aseptic surgery. In 1865, Lister successfully used carbolic acid as a surgical antiseptic; this innovation, applied in conjunction with heat sterilization, brought dramatic decreases in post-operative deaths. At the time of our article, Lister was serving as "surgeon extraordinary" to Queen Victoria.—*March 1898*

"No Way, Babe!"

75 YEARS AGO AS THE New York Yankees, who were tenants at the rival Giants' Polo Grounds, were erecting their own home, POPULAR SCIENCE described the new ballpark as "the greatest of modern amphitheaters." Measuring Yankee Stadium's dimensions, including a cavernous 461 feet to the center field wall, we predicted there would be no way Babe Ruth could knock a ball "out of the lot."—*March 1923*

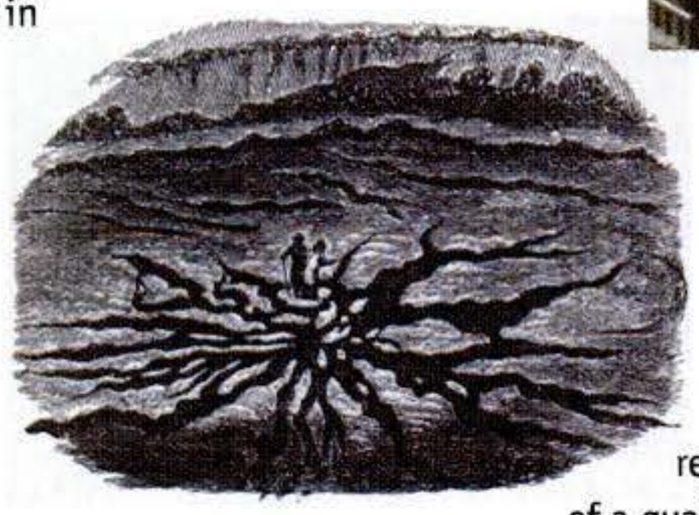
Though Ruth hit plenty of home runs at Yankee Stadium, none ever cleared the farthest wall in deep center field. Neither Ruth nor anyone else has ever hit a ball completely out of the stadium known as the "House That Ruth Built." Mickey Mantle, though, has come closest. In 1963, a still-rising shot from Mantle's bat hit the stadium's upper facade; estimates were that the blast would have traveled about 620 feet.



When Time Went Backward

25 YEARS AGO "I WAS THERE when they stopped the clock," wrote Science Editor Arthur Fisher, from Boulder, Colorado. What Fisher witnessed was the first leap second. Master clocks across the globe, including the National Bureau of Standards' clock in Boulder, were set back one second at midnight, June 30, making that day history's longest. This kept the new atom-based time scale in step with Earth's erratic rotation. —*March 1973*

Universal Coordinated Time was amended for the 21st time when the most recent leap second was added on June 30, 1997.



When the Earth Moved

125 YEARS AGO IN summarizing what was known about earthquakes, we reported that the first record of a quake in New England occurred 18 years after the Pilgrims landed. We cataloged the effects of quakes, including huge fissures (above). We also recalled our visit ["Measurement of Earthquake Waves," Sept. 1872] to the observatory of Luigi Palmieri near Italy's Mt. Vesuvius to see the seismograph he had invented.—*March 1873*

Rocket "Locomotive"

50 YEARS AGO USING 50,000 pounds of thrust developed by five massive rockets, experimenters sent a "locomotive" hurtling 1,019 mph down 2,000 feet of standard-gauge railroad track. The tests were made at California's Muroc Air Base by Northrop Aircraft to evaluate airplane shapes at supersonic speeds. The main problem: bringing the 15-foot aluminum-alloy sled to a halt.—*March 1948*

By 1954, researchers in the New Mexico desert were able to stop a similar rocket sled carrying a human at a speed of 632 mph in 1.4 seconds ["Lethal Force?" May '97].

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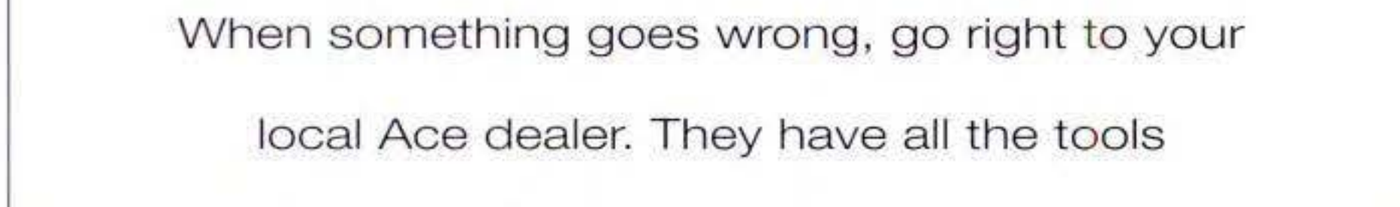

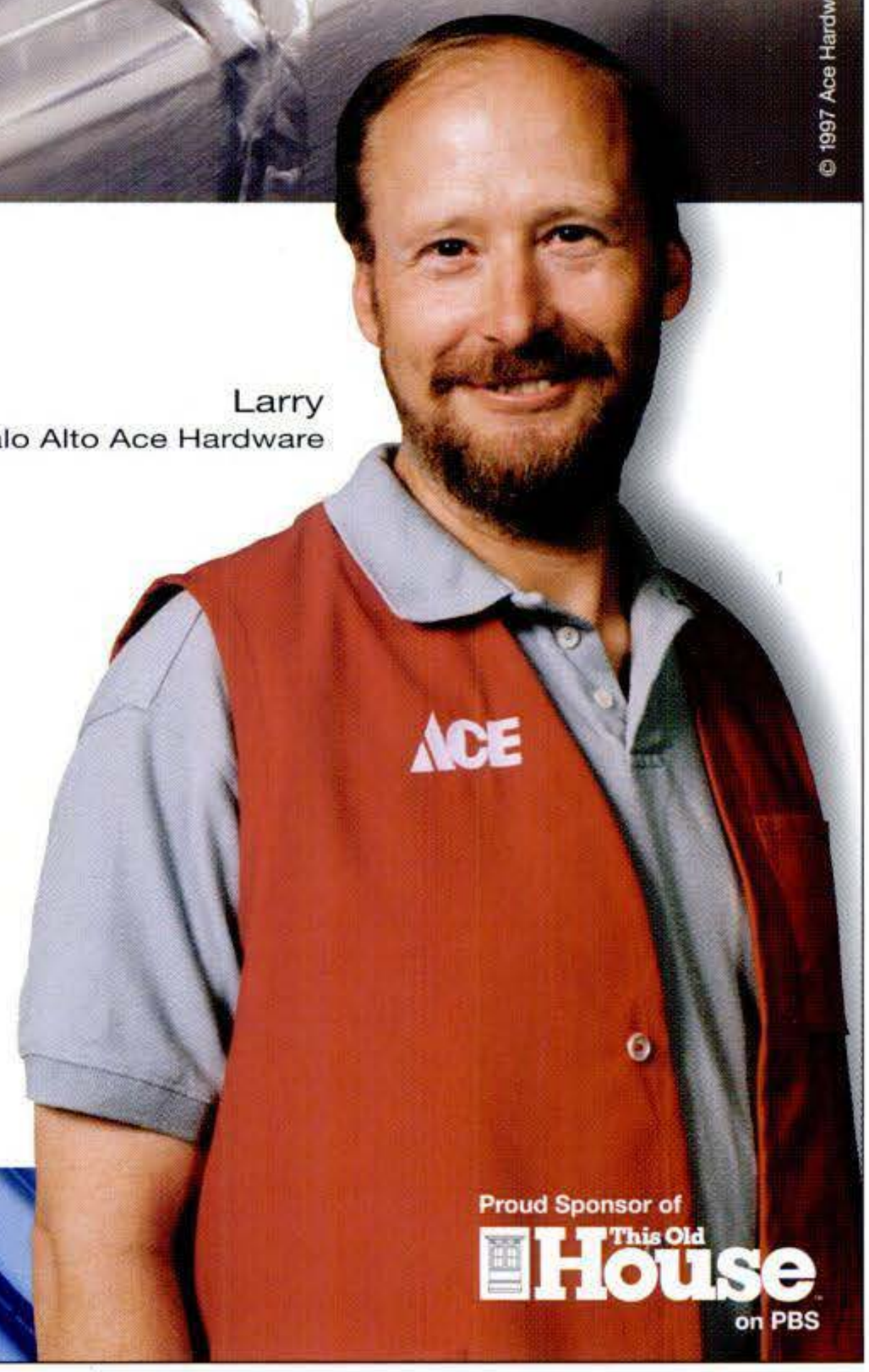

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